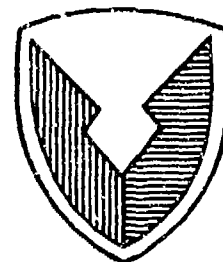




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MIGRATION OF HAZARDOUS SUBSTANCES THROUGH SOIL

Part II

Determination of the Leachability of Metals From Five
Industrial Wastes and Their Movement Within Soil

by

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August 1985

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Prepared for

U.S. Environmental Protection Agency
Hazardous Waste Environmental Research Laboratory
Cincinnati, OH 45268

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Samples of industrial wastes from the electroplating, inorganic pigment, nickel-cadmium battery, water-base paint, and chlorine production industries were characterized as to their composition, toxic metal content, and leaching characteristics using serial batch extractions and continuous flow columns. Distilled water was used as one solvent to simulate rainwater or ground water and municipal landfill leachate was used to simulate the effects of mixing industrial and municipal refuse in the same disposal site. The metal content (continued)		

19. KEY WORDS (continued):

Mercury	Kalkaska soil
Lead	Nicholson soil
Nickel	Leaching of wastes
Zinc	Serial batch leaching
Adsorption of metals	Continuous flow column leaching
Soil attenuation capacity	Release of metals
Anthony soil	Municipal landfill leachate
Chalmers soil	Drinking water standards
Davidson soil	Water pollution

20. ABSTRACT (continued):

of the waste leachate was measured before and after contact with the soil. The soils used were: Davidson, Chalmers, Nicholson, Anthony, and Kalkaska. The metals of interest were: cadmium, chromium, copper, mercury, lead, nickel, and zinc. The concentration of metals in waste and soil leachate were compared to published drinking water standards. It was found that the nickel-cadmium battery waste was extremely soluble and both water and municipal landfill leachate released extremely high concentrations of nickel and cadmium. These metals rapidly penetrated soil columns and would overwhelm the attenuation capacity of the soils underlying a disposal site. Substantial concentrations of cadmium and copper were released by water from the electroplating waste. The cadmium and the copper exceeded drinking water standards. Municipal landfill leachate solubilized more of the metals than did water. In addition, chromium was released by the municipal landfill leachate. The pigment waste released quite small concentrations of metals when both solvents were used although the municipal landfill leachate released more. The principal metals of concern from this waste were cadmium, chromium, and lead; these exceeded the drinking water standards in the soil column effluent. Zinc moved through the soil in substantial concentrations but did not exceed drinking water standards. Mercury was detected sporadically in very low concentrations. Water-base paint waste leaching was not complicated by heavy metal release. Zinc may be the only metal of concern and then only if the waste is co-disposed with municipal refuse. Chlorine production brine waste such as the sample used in this study may not be of concern if placed in segregated disposal. Mercury was only sporadically found in the soil column effluent when municipal landfill leachate was used as the solvent. It was also found that Davidson soil removed more metals from the waste leachate than did other soils with similar pH even though the other soils had higher clay contents, cation exchange capacities, and surface areas per unit weight. Since the Davidson soil had a much higher content of iron oxide than the other soils this suggests that iron oxide content of a soil may be a strong weighting factor in selecting soils for disposal sites.

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SECTION 1

INTRODUCTION

BACKGROUND

Normal industrial processes, along with air and water pollution abatement activities, are generating ever-increasing amounts of solid and semi-solid wastes that are placed in landfills and lagoons for disposal or indefinite storage. When these wastes are placed on land, hazardous substances contained in them may be released by leaching and/or decomposition and be free to move through soil, eventually finding their way into potable water supplies. Instances of adverse health effects due to migration of materials from land disposal sites into underground water have been documented and are of growing concern (1-4). Considering the actual damage that occurred in these instances and the potential threat of similar situations, the need for more careful management of land disposal is apparent.

OBJECTIVES

An important element in the improvement of land disposal is a knowledge of how wastes behave in the disposal environment and how any hazardous materials that may be released will move in soils. The overall objective of this study is to answer such questions for specific wastes both as a guide for focusing future disposal research on the most significant problems and also as an aid in identifying wastes requiring particular care upon disposal. An additional objective is to develop the techniques used in this work so that workable procedures may be made available for evaluating the leaching behavior of wastes at specific sites.

This study is not intended to provide definitive information on characteristics of wastes from specific industries or a definitive estimate of the environmental impact from disposing of such wastes on land. Since only one sample was taken from a single plant in each industry, the results are best used to identify the materials which may be of general concern in wastes from certain industries and to identify types of wastes and disposal conditions that may require special care to avoid adverse impacts.

EXPERIMENTAL PROCEDURES

Samples of industrial wastes from the electroplating, nickel-cadmium battery, inorganic pigment, water-base paint, and chlorine production industries were characterized as to their metal content and leaching characteristics, both in serial batch extractions and in continuous flow columns. Distilled water was used as one solvent to simulate the effect of rainwater or groundwater on the wastes. Municipal landfill leachate was used as the

other solvent to simulate the effect of mixing industrial and municipal wastes in the same disposal site. The resultant waste leachates were applied to small amounts of soil in batch studies and continuous-flow column studies. The metal content of the waste leachates was measured by atomic absorption spectrophotometry (AAS) before and after contact with the soils. Details of the analytical methods used to characterize the waste and quantitatively measure the metals in the leachates will be discussed in more detail elsewhere in this report.

To facilitate comparison of several methods for determining material released from wastes, this report discusses the study of waste leaching (Section 4) separately from the study of material movement in soil; enough information about the leachate composition (challenge) applied to the soil is repeated so that results are understandable. However, for complete information on the column study of any waste, the reader should refer to Section 4 for the types and amounts of materials solubilized from the waste and to Section 5 for the movement and retention of these materials in soil.

2. As expected, metals appeared in the water and MSW leachate extracts in the order cadmium, copper, zinc, and nickel.
3. For water leaching, chromium was detected in the batch extracts but not in the effluent from the columns.
4. When MSW leachate was used, chromium was detected both in batch extracts and column effluents.
5. Metal concentrations in water extracts were:
 - cadmium 0.8 ug/ml to 2.1 ug/ml
 - copper 0.5 ug/ml to 2.6 ug/ml
 - nickel 0.5 ug/ml to 2.5 ug/ml
 - zinc 0.5 ug/ml to 3.5 ug/ml
6. Metal concentrations in MSW leachate extracts were:
 - cadmium 2.2 ug/ml to 6.0 ug/ml
 - copper 1.9 ug/ml to 3.2 ug/ml
 - nickel 1.2 ug/ml to 1.5 ug/ml
 - zinc 3.3 ug/ml throughout the leaching period
7. Zinc concentrations in the MSW leachate extract were lower than in the original MSW leachate (60 ug/ml). It is not known whether the zinc in the extract came only from the waste or from the waste and the MSW leachate.

Inorganic Pigment Waste

1. The metals content of this waste was approximately the same as the electroplating waste but the metals in this waste were much less soluble. This may be due to the organic flocculating polymer that was added during treatment of waste water at the pigment plant.
2. Metal concentrations in water extracts were:
 - chromium 1.0 ug/ml to 4.5 ug/ml
 - cadmium 0.05 ug/ml to 0.3 ug/ml
 - copper 0.1 ug/ml to 0.3 ug/ml
 - nickel 0.05 ug/ml to 0.6 ug/ml

Lead was found only sporadically in the water extract.
3. Metal concentrations in MSW leachate extracts were:
 - chromium 0.75 ug/ml to 1.5 ug/ml
 - lead 0.5 ug/ml to 1.0 ug/ml
 - cadmium 0.3 ug/ml to 1.3 ug/ml
 - copper 0.3 ug/ml to 1.8 ug/ml
 - zinc 0.4 ug/ml to 2.0 ug/ml
 - nickel 0.3 ug/ml to 1.1 ug/ml
4. As was found for the electroplating waste, zinc concentrations in the MSW extract of the pigment waste were lower than in the original MSW leachate.

SECTION 2

CONCLUSIONS

GENERAL

1. Waste characteristics such as pH, total metal content etc. were marginally useful predictors of metal concentrations in water or municipal solid waste landfill (MSW) leachate extracts of the wastes; no satisfactory substitute for leaching tests, either by batch or column procedures, was found.
2. Waste and extract characteristics such as pH, electrical conductivity, and metal content, were useful predictor of metal movement in soils.
3. MSW leachate solubilized much greater amounts of metals from all wastes than did distilled water.
4. Metals moved more rapidly through soils when contained in MSW leachate than when contained in water.

LEACHING BEHAVIOR OF THE WASTES

Nickel-Cadmium Battery Waste

1. In water extracts of this waste, nickel concentrations ranged from less than the detection limit 0.1 ug/ml to 60 ug/ml; cadmium concentrations ranged from 50 ug/ml to 3500 ug/ml.
2. In MSW leachate extracts of this waste, nickel concentrations ranged from 35 ug/ml to 70 ug/ml. These levels were higher than observed in water extracts. Cadmium was leached at nearly a constant level of 2750 ug/ml.
3. The generator of this waste reported that most of it was recycled because of the cost of cadmium; in order to obtain a sufficient quantity of the waste used in this study it was necessary to obtain two samples from the generator.

Electroplating Waste

1. All metals present in the electroplating wastes were found in water and MSW leachate extracts at low (0.5 ug/ml to 6.0 ug/ml) but appreciable concentrations.

Water Base Paint Waste

1. Water extracts of the paint waste contained lower concentrations of metals than water extracts of any other waste. Zinc, chromium, and copper were the only metals present in significant concentrations.
2. Metal concentrations in water extracts of the paint waste were:
 - chromium 0.05 ug/ml to 0.15 ug/ml
 - zinc 0.02 ug/ml to 0.75 ug/ml
 - copper 0.02 ug/ml to 0.25 ug/mlCadmium, lead, and nickel were found only sporadically and could not be accurately quantified.
3. MSW leachate extracted greater amounts of each metal (except for chromium) from the paint waste than did water.
4. Metal concentrations in the MSW leachate extract were:
 - zinc 40 ug/ml to 230 ug/ml
 - lead 1.5 ug/ml to 3.5 ug/ml
 - cadmium 0.05 ug/ml to 1.5 ug/ml
 - mercury 0.02 ug/ml to 0.15 ug/ml
 - chromium 0.08 ug/ml to 0.1 ug/ml
 - copper 0.1 ug/ml to 0.25 ug/ml
 - nickel 0.25 to 0.3 ug/ml throughout the leaching period
5. This was the only waste for which the MSW leachate extract contained greater concentrations of zinc than the original MSW leachate.

Chlorine Production Brine Waste

1. Mercury was the only metal (of those listed of concern) leached from this waste in detectable concentrations. However, the metal was only occasionally detected.
2. Total and leachable concentrations of mercury in this waste may be low because of advanced wastewater treatment procedures employed at the plant where the waste was collected. Similar wastes from other sources may contain greater amounts of mercury (see Section 5).

MOBILITY OF WASTE COMPONENTS IN SOILS

In the following, "soil column effluent" means either water or MSW leachate that has passed through a column of waste and then through a column of soil connected to the outflow end of the waste column.

Zinc

1. Although zinc was present at low concentrations in water and MSW leachate extracts of most wastes it was found in higher concentrations in soil column effluents than most of the other metals.

2. The most plausible mechanism for this behavior is displacement of native soil zinc by major cations (e.g. calcium and magnesium) in effluents from the waste columns.
3. Judged on the basis of the ratio of zinc in the soil column effluent/ zinc in the solution applied to the soil, zinc would be the major metal released from land disposal of any of the wastes studied. However, it must be realized that zinc is much less toxic than the other metals studied and much of the zinc in the soil column effluents comes from the soil itself rather than the waste.

Other Metals

1. In most cases, cadmium and nickel were next greatest in order of amount found in the soil column effluents.
 cadmium 0.05 ug/ml to 3000 ug/ml
 nickel 0.05 ug/ml to 40 ug/ml
2. When the waste/soil columns were leached with water, very small amounts of lead were found in the soil column effluent (0.1 ug/ml to 0.5 ug/ml).
3. When MSW leachate was used, lead was found in amounts slightly less than cadmium and nickel.
4. Copper and chromium were found in very small concentrations in soil column effluent and then only in the columns where water base paint waste and MSW leachate were used.
 copper 0.003 ug/ml to 0.2 ug/ml
 chromium 0.06 ug/ml to 0.1 ug/ml

RANKING OF WASTES

On the basis of amounts of metals released from the waste and the potential for metal movement in soil, the wastes in this study would be ranked as follows (the ranking decreases in potential for metal release and movement):

Nickel-Cadmium Battery Production Waste
 Electroplating Waste
 Inorganic Pigment Waste
 Water Base Paint Waste
 Chlorine Production Brine Waste

ADDITIONAL CONCLUSIONS

1. The Davidson soil removed more metals from the waste leachates than did other soils with similar pH, even though the other soils had higher clay contents, cation exchange capacities, and surface area per unit weight. Because iron oxide content was higher in the Davidson than in the other soils, iron oxide content may be a useful site selection criterion for disposal facilities.

2. Serial batch extractions gave leaching data that were quite similar to data obtained from the slower and less convenient column leaching procedure. Batch and column leaching have not been compared for oily or amorphous wastes.
3. Mixing alkaline metal-bearing wastes with acidic materials such as MSW leachate can release large quantities of metals from the wastes.
4. Neutral to alkaline soils controlled metal movement better than acid soils.

SECTION 3

RECOMMENDATIONS

When planning for disposal of highly soluble, metal-bearing wastes such as the nickel-cadmium battery waste, the total amount of metals that may be released and the predicted attenuation capacity of the underlying soil should be carefully examined to avoid unexpectedly rapid migration.

Site and waste specific studies should be conducted with actual wastes and soils whenever metal bearing wastes are to be placed in land disposal sites where the soil attenuation capacity is a factor in the design of the site.

Field studies should be conducted to determine if co-disposal of municipal and industrial wastes results in adverse impacts as suggested by the results of this study.

Additional work should be conducted on rapid batch testing, extrapolation of laboratory results to field conditions, and on the effect of mixing two or more industrial wastes in the same disposal site.

SECTION 4

WASTE CHARACTERIZATION AND LEACHING STUDIES

COLLECTION AND CHARACTERIZATION OF WASTES

Introduction

Five industrial waste samples were collected and used in this study. The waste samples were characterized primarily for their metal content and the tendency for solubilization of hazardous metals from the wastes. Other analyses, such as measurement of chloride, carbonate, conductance, etc. were also performed. The analyses were done to help with the waste characterization and to assist with the explanation of how the nature of the wastes affect metal migration or fixation in the soils.

Each plant had already instituted controls which largely reduce the possibility of contamination of ground or surface water. These companies either hold the treated wastes or, if economically feasible, recycle the wastes back into the process (e.g., it is feasible for a nickel-cadmium battery manufacturer to recover these metals, especially cadmium). However, if controlled processes are not used, considerable contamination of water could result either through runoff or migration through soil, particularly, if wastes were disposed of or found their way into an acidic environment.

The process or control procedures used at four of the plants generate alkaline wastes with many of the metals precipitated as the hydroxides with sodium or potassium hydroxide. However, many of the metals may exist or are converted to the carbonate salt, especially as the alkaline waste ages. The solubilities of these salts in water are very low. Table 1 lists the solubility products of some of the metal hydroxides of interest and the corresponding metal concentrations when equilibrated in water.

Electroplating Waste

Description--

Wastes from plating, phosphatizing, and metal cleaning operations at an electroplating plant are treated in a variety of ways that depend upon the specific process in use. The disposal of wastes also varies widely from plant to plant. This is thoroughly discussed elsewhere (5). The following are brief descriptions of the waste treatments which generated the waste samples used in this study.

TABLE 1. SOLUBILITY PRODUCT OF SOME METAL HYDROXIDES OF INTEREST

Metal Hydroxide	K_{sp}	Concentration of Metal (mg/l)
Cadmium	2×10^{-14}	1.9
Chromium (ic)	4×10^{-31}	0.0007
Copper (ic)	1.6×10^{-19}	0.022
Lead (ic)	4×10^{-15}	1.76
Mercury (ic)	3×10^{-26}	0.0004
Nickel (ic)	1.6×10^{-16}	0.201
Zinc	5×10^{-17}	0.15

Soluble cyanides in other electroplating wastes are destroyed by raising the pH by the addition of caustic soda and treatment with chlorine (continuous process) or sodium hypochlorite (batch process).

Hexavalent chromium is reduced to trivalent chromium by treatment at a pH of 3.0 or less with sulfur dioxide (continuous process) or sodium metabisulfite (batch process). The pH is then raised to 8.0 with caustic soda or lime to precipitate the trivalent chromium, which settles as a sludge in a cement-lined holding lagoon.

Sludge is removed periodically from the holding lagoons and trucked to a holding area, where it is spread to dry. The sample used in this study was collected from several points of the holding area where fresh waste had been recently spread.

Analysis--

Semiquantitative and qualitative analyses for metal composition were obtained by x-ray fluorescence. Samples were prepared for quantitative analysis by heating in a mixture of 10 milliliters of 10 percent ammonium citrate and 10 milliliters concentrated nitric acid; a solid residue remained. The supernatant solution was removed, evaporated to dryness and redissolved in water. To this aqueous solution, 1 milliliter concentrated nitric acid and 1 milliliter 10 percent ammonium citrate were added. A blank was prepared in the same manner.

The residue remaining after digestion with ammonium citrate and nitric acid was determined to be primarily silica. Some potassium, iron, copper, and titanium were also found. Treatment with aqua regia did not change the residue composition. Results are shown in Table 2.

TABLE 2. METAL ANALYSIS OF THE ELECTROPLATING WASTE

Element	Percent by Weight
Chromium	10.5
Copper	3.2
Zinc	1.0
Cadmium	0.8
Nickel	1.0*
Iron	2.0*
Manganese	2.0*

* Semiquantitative results - aluminum, phosphorus, potassium, calcium and silica were also present.

The soluble chloride content of the waste was determined by the Mohr Titration Method, using a solution prepared by mixing 1 gram of waste with 20 milliliters of distilled water and stirring for 2 hours. The mixture was filtered and analyzed. The chloride content of the waste was found to be 0.4 percent.

The carbonate content was determined by adding sulfuric acid to 25 milligrams of waste and collecting the CO_2 evolved in standardized $\text{Ba}(\text{OH})_2$ solution. The excess $\text{Ba}(\text{OH})_2$ was titrated with 0.1 N HCl. The carbonate content was found to be 2.2 percent.

The electroplating waste is slightly alkaline when mixed with distilled water. Attempts were made to measure the waste alkalinity directly by stirring a small amount (less than 1.0 gram) of waste in distilled water and titrating the slurry with standardized acid (0.087 N HCl). However, the acid consuming capacity of the waste was such that stable pH readings could not be obtained. As a result, this approach was rejected and the alkalinity was estimated using an extract made by mixing 20 grams of dry waste with 200 milliliters of distilled water. The initial pH was measured at 7.2. The beaker was covered and stirred for 72 hours, after which time the pH was 7.35. A 50 milliliter aliquot was filtered and the alkalinity was measured by titrating with 0.087 N HCl. The titration proceeded

smoothly and was carried to pH 3.7 as recommended in Standard Methods (6). The alkalinity was found to be 1.65×10^{-5} equivalents of acid/gram of dry waste. The titration curve is shown in Figure 1.

Interpretation of alkalinity results obtained from an industrial waste in terms of specific chemical components (hydroxide, carbonate, bicarbonate) is questionable. Alkalinity indicated only gross characteristics of the sample and represents the summation of all components wholly or partially titrated.

Another 20-gram portion of electroplating waste was mixed with 200 milliliters of municipal landfill leachate and stirred for 72 hours. A 50-milliliter aliquot was filtered and titrated to pH 3.7. A 50-milliliter aliquot of landfill leachate was also titrated in the same manner. The alkalinity of the leachate alone was found to be 1.63×10^{-3} equivalents of acid/milliliter of leachate, while the alkalinity of the waste extract was 1.57×10^{-3} equivalents of acid/milliliter of extract. This indicates that the waste had little effect upon the alkalinity of the leachate at this mixing ratio and demonstrates its buffer capacity. The results obtained from the two titrations are shown in Figure 2.

To describe municipal landfill leachate in terms of alkalinity is somewhat meaningless because of the "as-is" acidity and the complexity of its composition. However, this was done to establish a basis for comparison between waste extracts prepared from water and municipal landfill leachate.

Cyanide content in the waste was measured using a modification of the method described in Standard Methods (7). Only a trace of cyanide was found.

Nickel-Cadmium Battery Production Waste

Description--

Waste from the production of nickel-cadmium batteries arises from the washing of screens (electrodes) upon which nickel and cadmium have been fixed by precipitation from nitrate salt solutions by adjusting the pH to 11 to 12 with sodium hydroxide. The spent solution (containing nickel or cadmium hydroxide precipitates) is drained off, and the screens are washed with water. The alkalinity of the washwater is maintained at pH 11 to 12 to promote precipitation of the two metals from solution. The wash water is held in holding tanks and the metal hydroxides settle (samples were collected at this point), and the supernatant solution is pumped into a waste lagoon. Although most of the nickel and cadmium had been precipitated from the wash water, a small amount of each is discharged into the lagoon.

Analysis--

Quantitative, semiquantitative, and qualitative analyses of the waste were completed. The sample used in quantitative analyses was prepared by dissolving the waste in 1:1 nitric acid, evaporating to dryness and redissolving in water. Trace metals were determined by x-ray fluorescence. Results are shown in Table 3.

TABLE 3. METAL ANALYSIS OF NICKEL-CADMIUM BATTERY PRODUCTION WASTE

Element	Percent by Weight
Nickel	10.1
Cadmium	51.0
Copper	0.5*
Iron	0.9*

* Indicates semiquantitative results

The chloride content of the nickel-cadmium waste was found to be 0.16 percent. The carbonate content was also 0.16 percent.

A 50-milliliter aliquot was taken from an extract prepared by adding 20 grams of waste to 200 milliliters of water and mixing 72 hours. The filtered aliquot was titrated with acid to pH 3.7. The alkalinity was found to be 9.5×10^{-4} equivalent of acid/gram of dry waste. The titration curve is given in Figure 3 and shows considerable hydroxide and carbonate alkalinity present in the sample extract. This was expected and is consistent with observations made while collecting the sample and with the industrial process which generates the waste.

Another portion of waste was added to municipal landfill leachate and treated as described above. A 50-milliliter aliquot was titrated with standard acid. The results are shown in Figure 4.

Nickel-cadmium battery waste caused considerable change in municipal landfill leachate. The pH of the leachate was raised from 5.6 to 8.5. Considerably more acid was required in the titration to reduce the pH to 3.7 than was required for the leachate alone. However, by comparing the titration curve for leachate waste extract with the distilled water curve (Figure 3), it can be seen that the volume of titrant used to reach the desired pH is not additive. The distilled water extract titration required 53 milliliters to reach pH 3.7. Municipal landfill leachate alone required 80 milliliters. However, titration of the municipal landfill leachate extract titration required 100 milliliters instead of the expected 133 milliliters of acid. This further demonstrated that leachate is a complex solvent and cannot be described simply in terms of alkalinity/acidity.

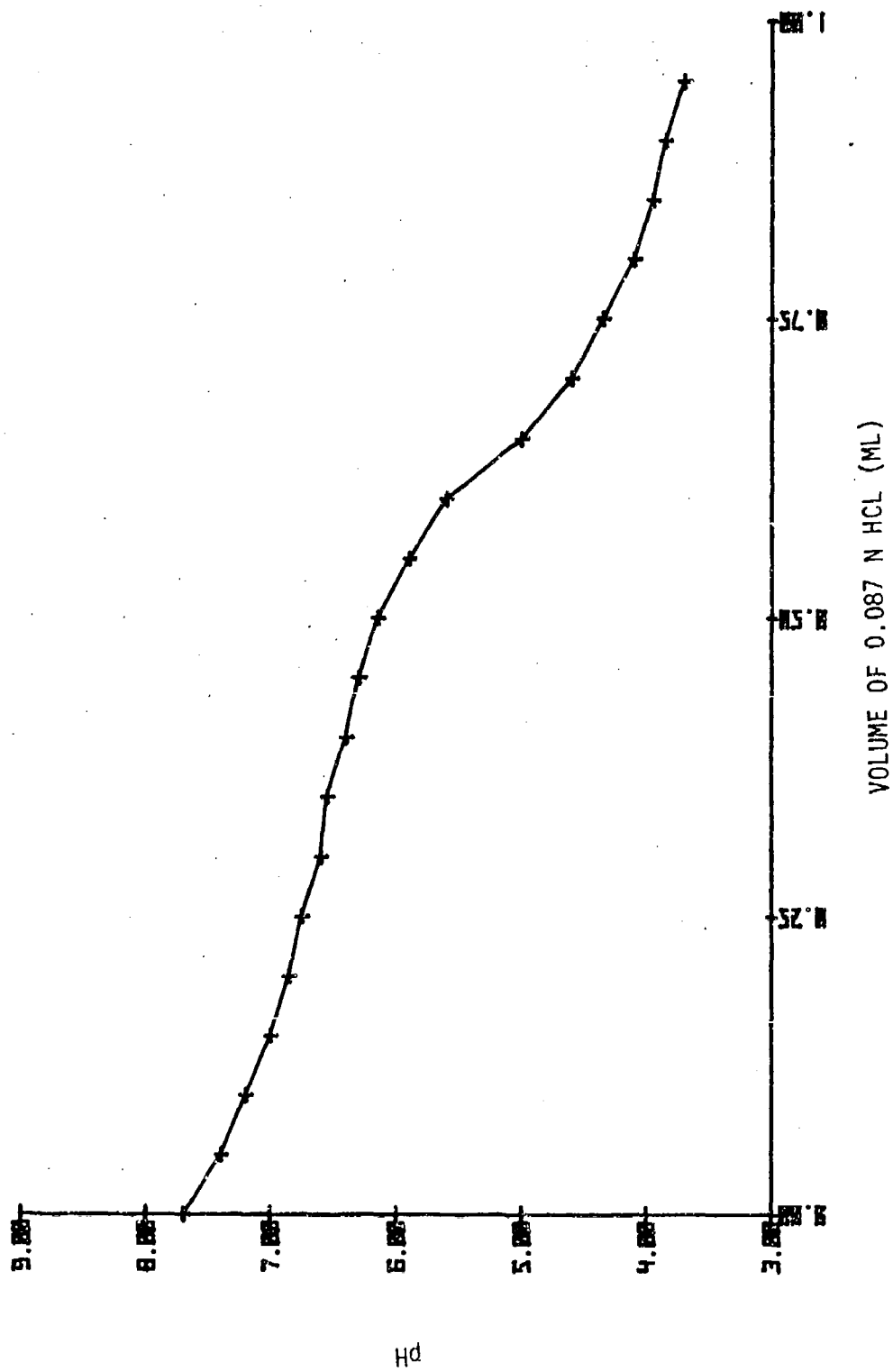


FIGURE 1: TITRATION CURVE FOR WATER EXTRACT OF ELECTROPLATING WASTE

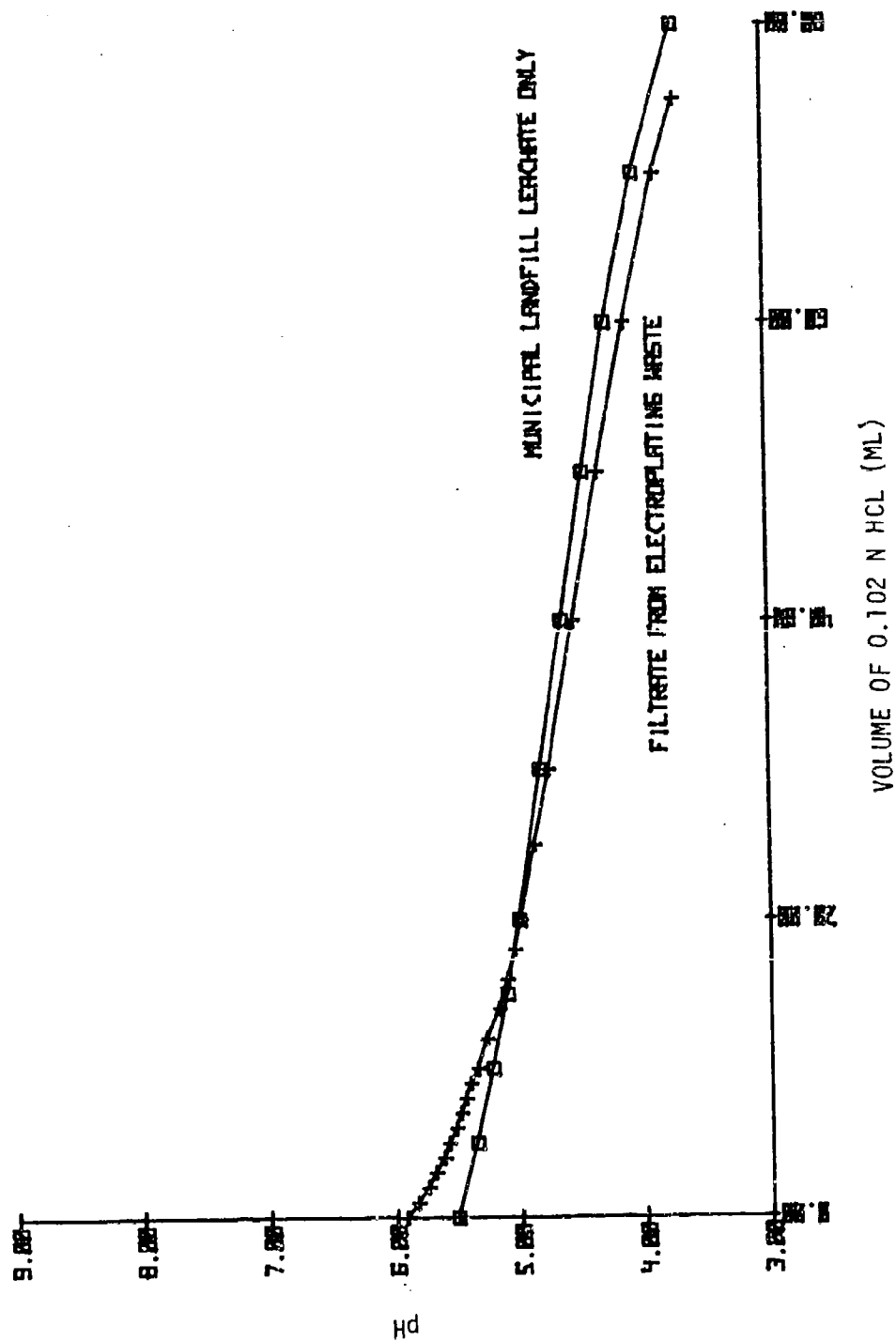


FIGURE 2: TITRATION CURVE FOR MUNICIPAL LANDFILL LEACHATE EXTRACT OF ELECTROPLATING WASTE AND MUNICIPAL LANDFILL LEACHATE ONLY

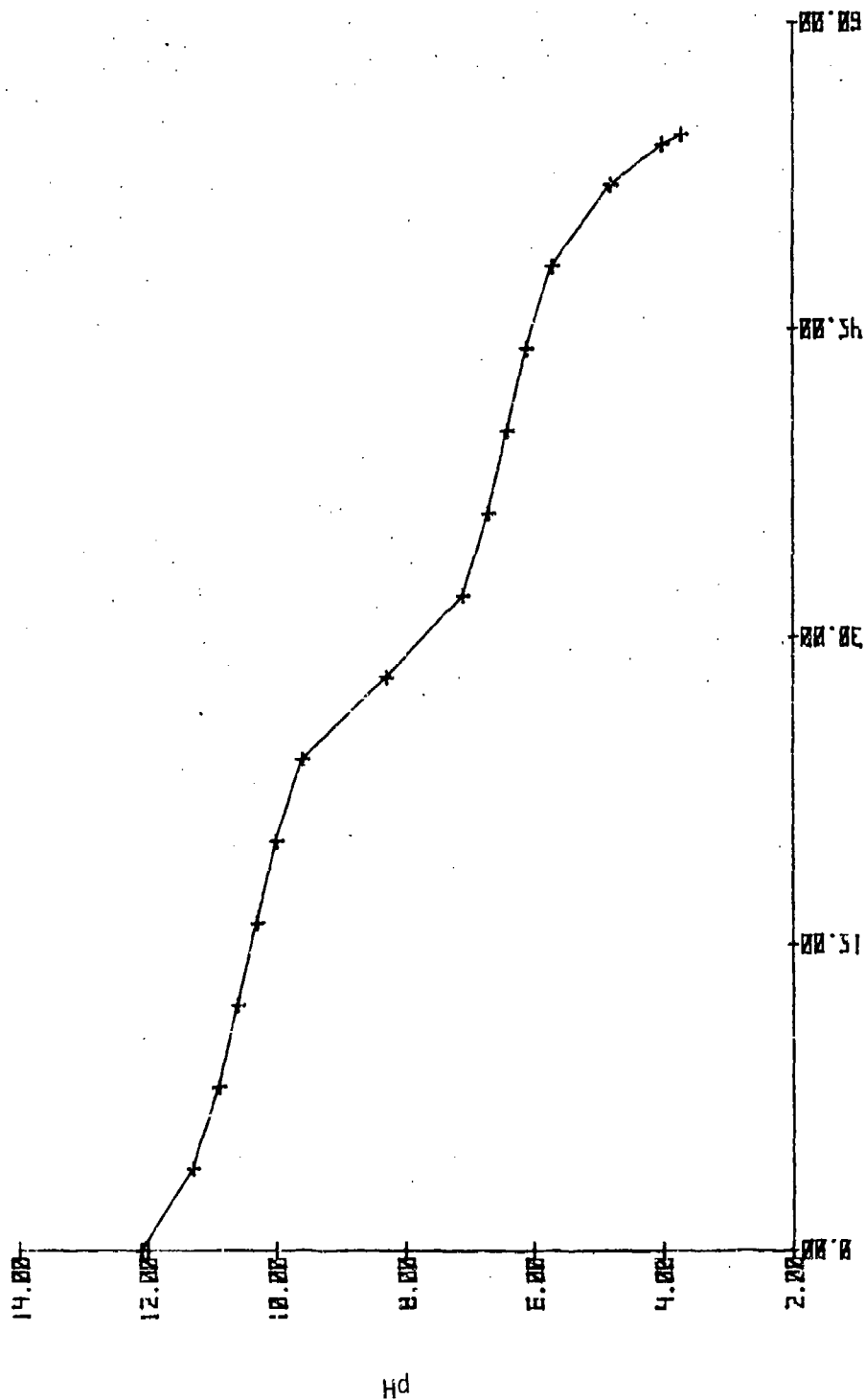


FIGURE 3: TITRATION CURVE FOR WATER EXTRACT OF NI-CD BATTERY WASTE

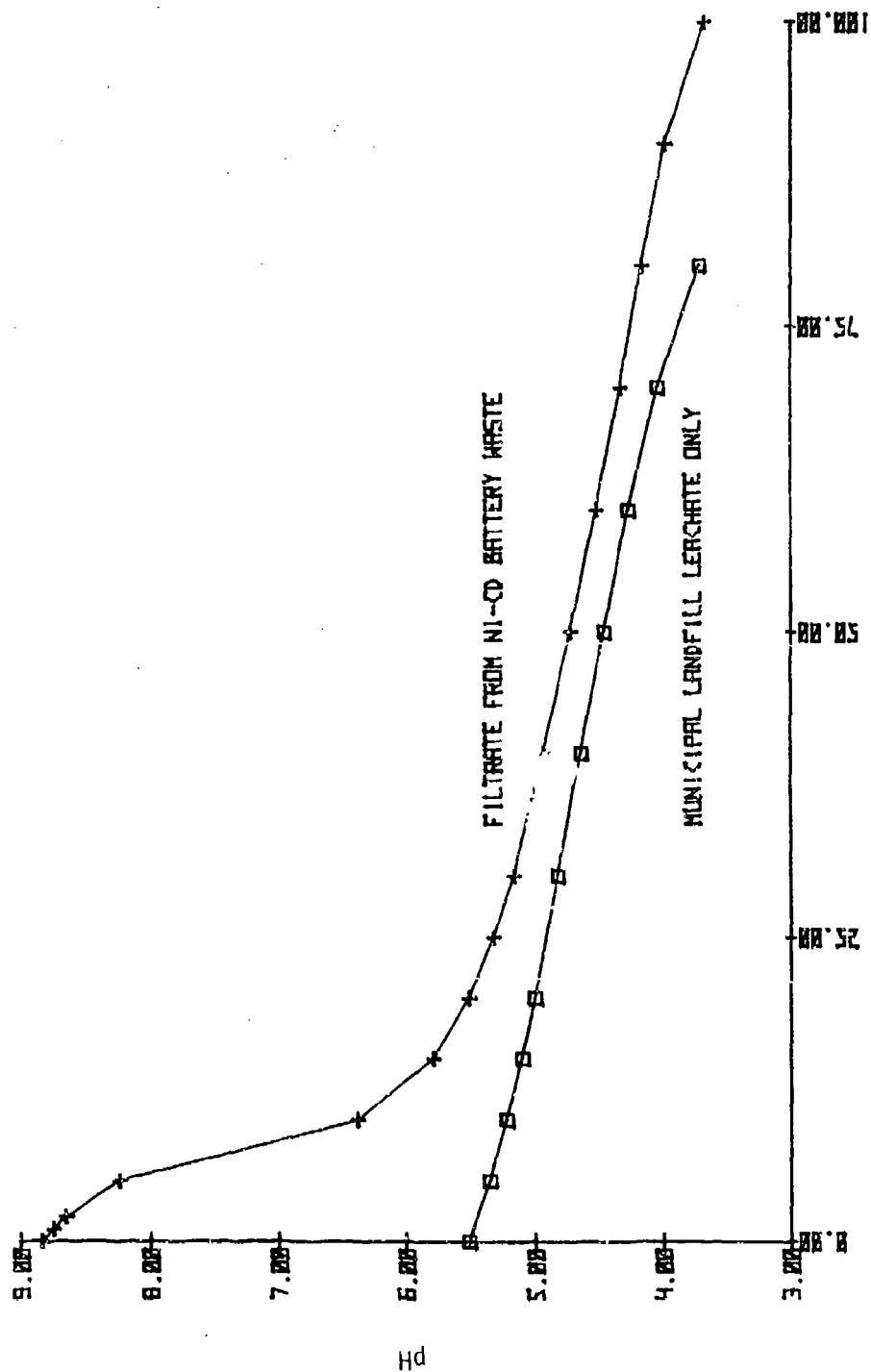


FIGURE 4: TITRATION CURVE FOR MUNICIPAL LANDFILL, LEACHATE EXTRACT OF NI-CD BATTERY WASTE AND MUNICIPAL LANDFILL LEACHATE ONLY

Inorganic Pigment Waste

Description--

The type of waste generated (metals present) is dependent upon the pigment(s) manufactured at a specific plant. Pollution-abatement processes have been instituted at many pigment and paint production plants and it is expected that more will do so in the future. However, the abatement process and waste disposal practices vary. These have been discussed extensively elsewhere (8). The following describes only the process used at the plant where the sample used in this study was collected. Wastewater from the plant contains approximately 700 ppm of dissolved solids from equipment cleanup, spills, etc. The water stream is mixed with sulfuric acid to bring the acidity to pH 3. This is followed by a sulfur dioxide treatment to reduce hexavalent chromium. The solution is then pumped into a large neutralization tank, and the pH is adjusted to 8 with slaked lime. The mixture is then pumped to another tank where sodium sulfide is added. After mixing, the excess sulfide ion is precipitated by addition of ferrous sulfate, and the mixture is pumped to a settling tank. During the pumping operation, a flocculating polymer (Swift's X-200) is added. The precipitate in the settling tank is sent to a filter press while the liquid is pumped through sand filters and discharged. The sand filters are periodically backflushed into the neutralization tank and the above procedure is repeated. Solid waste in the filter press is pressed at 150 psi and forms greenish black filter cakes which are approximately 30 percent solids. The cakes are then hauled to a dump. Ions of interest in the waste are cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc.

Analysis--

Quantitative and semiquantitative analyses of the wastes were completed. The sample was prepared by fusing the waste with sodium peroxide at low heat. The fused sample was dissolved in hot water and acidified with nitric and hydrochloric acids. The sample was diluted to 100 milliliters. Appropriate aliquots were taken and analyzed by AAS. Semiquantitative analyses were obtained by either AAS or X-ray fluorescence. Results are shown in Table 4.

Alkalinity of the waste was determined by taking a 50 milliliter filtered aliquot of a sample prepared by mixing 20 grams of waste and 200 milliliters of water for 72 hours. The filtrate was titrated with 0.087 N HCl and the titration proceeded smoothly to pH 3.7. Alkalinity was 1.22×10^{-4} equivalents of acid/gram of dry waste. The titration curve is shown in Figure 5.

Another sample of the waste was mixed with municipal landfill leachate and the titration was repeated. The results (plotted in Figure 6) show that the pigment waste produced a significant change in the municipal landfill leachate. Considerably more acid was required to reach pH 3.7 than was required when the original leachate was titrated.

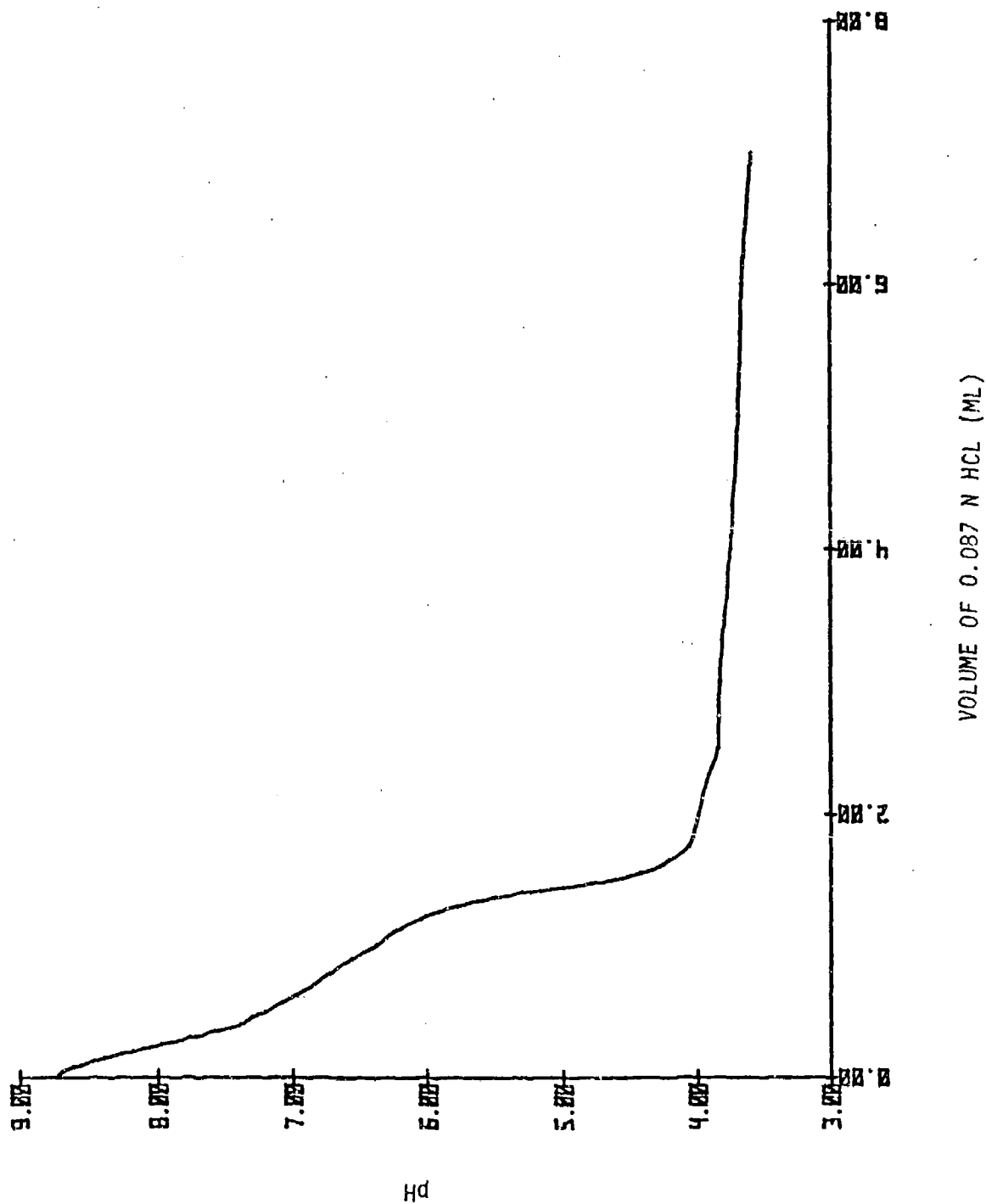


FIGURE 5: TITRATION CURVE FOR WATER EXTRACT OF INORGANIC PIGMENT WASTE

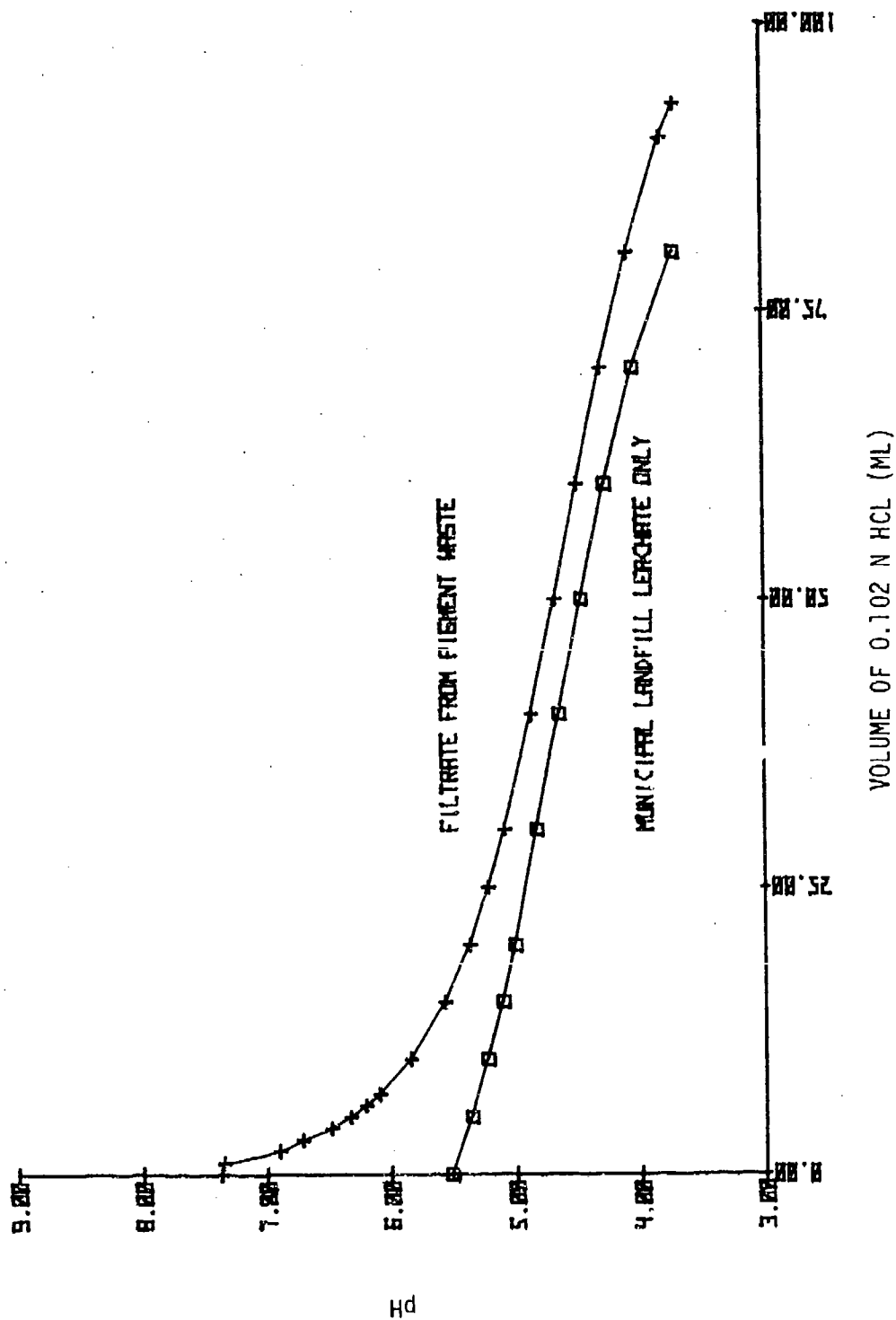


FIGURE 6: TITRATION CURVE FOR MUNICIPAL LANDFILL LEACHATE EXTRACT OF INORGANIC PIGMENT WASTE AND MUNICIPAL LANDFILL LEACHATE ONLY

TABLE 4. METAL ANALYSIS OF INORGANIC PIGMENT WASTE

Element	Percent by Weight
Chromium	7.0
Cadmium	0.17
Copper	0.42
Zinc	0.08
Lead	6.2
Mercury	0.0001
Selenium	0.05
Calcium*	6.0
Titanium*	0.2
Barium*	13.0
Iron*	10.0
Silicon*	1.0

* Indicates semiquantitative results

The chloride content of the waste was 0.01 percent. Carbonate content was 3.8 percent.

Cyanide was measured using the standard method previously cited (reference 7). It was 2.2 percent. An attempt was made to differentiate between simple cyanide salts and complexed cyanide. The waste sample was mixed with acid in a distillation flask and distilled for 1 hour. The distillate and cyanide were collected in a caustic trap. The trap was removed and the cyanide content was measured. A fresh caustic trap was then attached to the distillation apparatus, mercuric and magnesium chloride were added to the distillation flask (these salts are required to break cyanide complexes) and distillation was continued for an additional hour. The caustic trap was removed and no cyanide was found. This indicates that the cyanide was present in the sample as simple salts.

Total carbon content of the pigment was determined by C,N,H analysis. Organic carbon is converted to CO_2 in oxidation furnaces at a temperature of 1050 to 1100° C and carbonate salts are decomposed into CO_2 and oxides. In order to determine the percent carbon due to organic compounds in the samples, a correction must be made for the carbon due to carbonates.

Total carbon percentage in pigment sludge was 6.14; carbon due to carbonate was determined to be .76 percent, leaving a total percentage of organic carbon in the pigment sludge of 5.38.

Water Base Paint Waste

Description--

A water base paint waste was collected. The treatment which produces the waste is as follows. Waste and wash down water are treated with sodium sulfate and agitated. Lime is added to adjust the pH to 10 or greater. Alum is then added, followed by a flocculating polymer. The mixture is finally

drained into a settling tank. The liquid is discharged and the solids are pumped into a small lagoon. A sample was obtained from this location as grayish air-dried chunks. The metals of interest in this sample are cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc.

Analysis--

The waste composition was analyzed by fusing the sample with sodium bisulfate at red heat. The fused sample was dissolved in hot water, acidified with nitric and hydrochloric acids, and diluted to 100 milliliters. The results of the quantitative analysis for metals of interest are shown in Table 5.

The chloride content was 0.045 percent; carbonate content was 11 percent.

The alkalinity of the waste was determined in the same manner as described for paint waste and was 9.14×10^{-6} equivalents of acid/gram of sludge. The titration curve is shown in Figure 7. This was repeated using municipal landfill leachate and the results are plotted in Figure 8.

Comparing Figures 7 and 8, it can be seen that municipal landfill leachate produces a significantly different extract than that obtained from water. The initial pH of the water extract was approximately 8.5, while the municipal landfill leachate extract pH was 5.9

Cyanide content was measured using the method described for inorganic pigment; it was 0.03 percent.

The total carbon percentage was 30.8; carbon due to carbonates was determined to be 2.2 percent, leaving a total percentage of organic carbon in the paint sludge of 28.6.

Chlorine Production Brine Waste

Description--

The plant from which this sample was obtained produces 330 tons of chlorine per day by the mercury cell process resulting in the production of over 17,000 pounds/day of waste material. The sodium chloride used to prepare the brine solution for the mercury cell comes from the Louisiana salt domes and contains about 1.1 percent calcium sulfate, 0.01 percent calcium chloride and 0.3 percent insoluble impurities. Impurities are removed before electrolysis. The concentrated brine is fed into the mercury cell, where chlorine is liberated at one electrode, and sodium-mercury amalgam is formed at the other. The spent brines emerging from the electrolysis cells are treated, and the mercury is precipitated as the brine is concentrated and recycled. About 80 percent of the waste produced at the plant originates from the brine saturator; the remaining

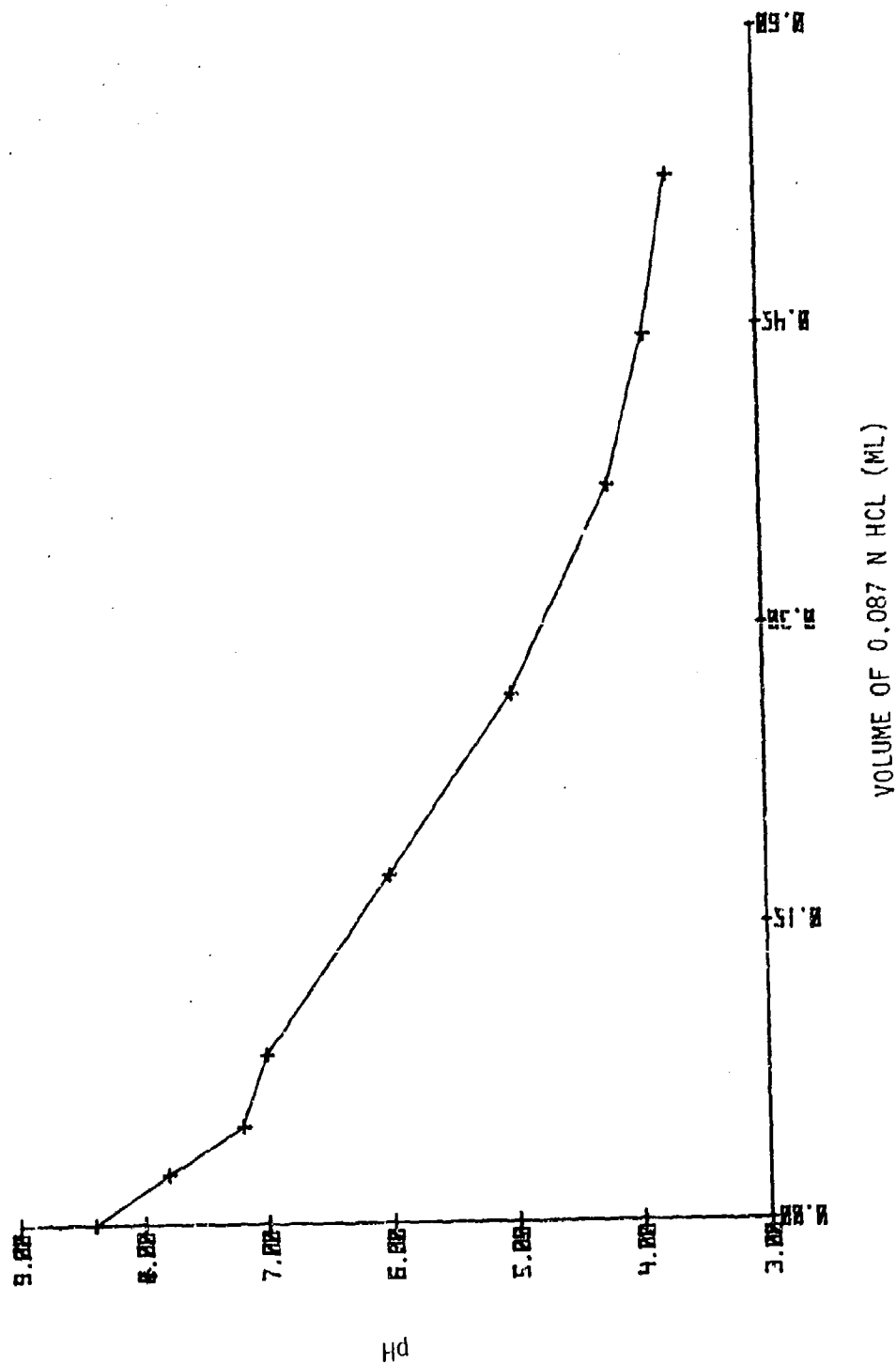


FIGURE 7: TITRATION CURVE FOR WATER EXTRACT OF WATER BASE PAINT WASTE

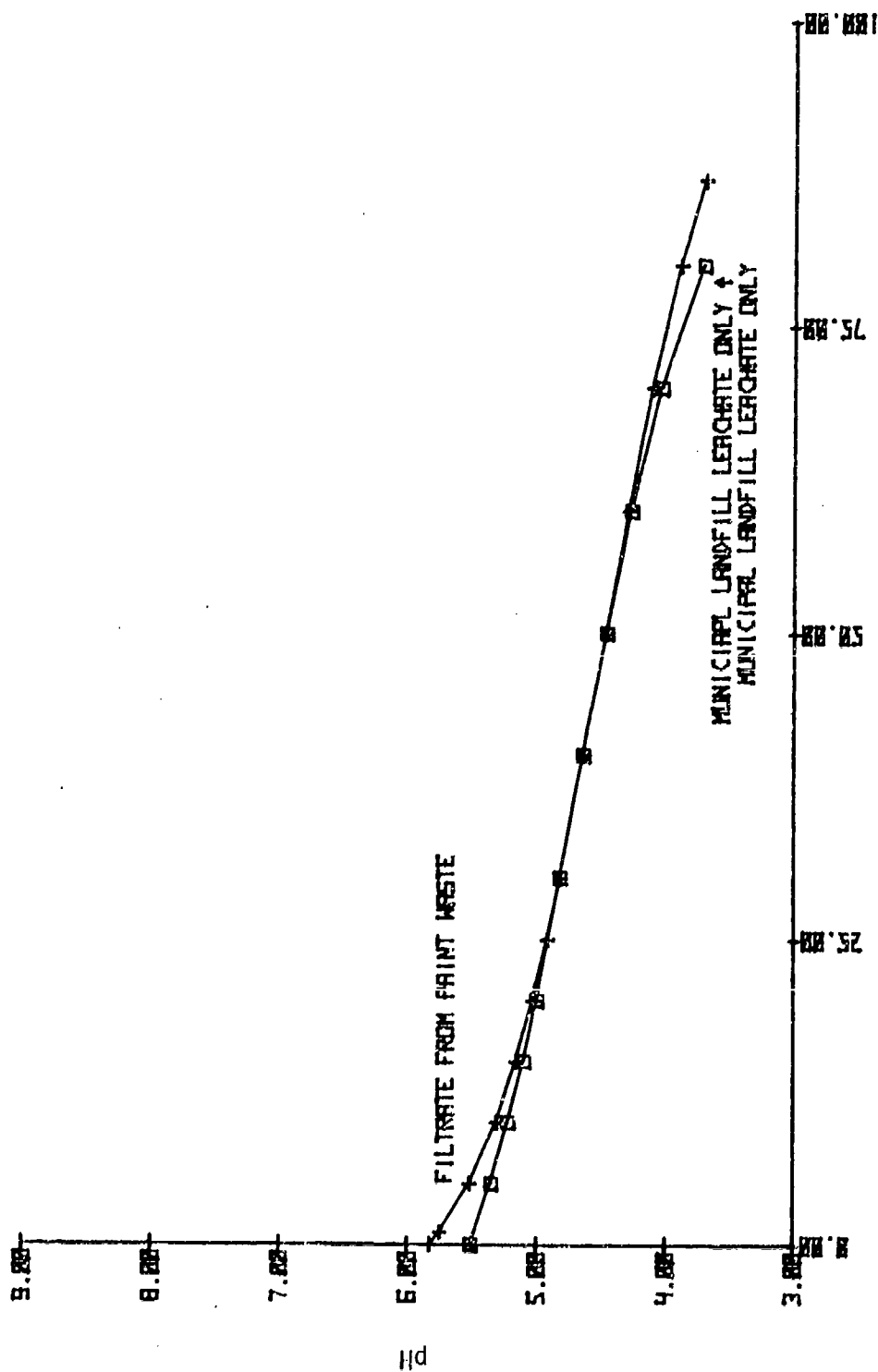


FIGURE 8: TITRATION CURVE FOR MUNICIPAL LANDFILL LEACHATE EXTRACT OF WATER BASE PAINT AND MUNICIPAL LANDFILL LEACHATE ONLY

TABLE 5. METAL ANALYSIS OF WATER BASE PAINT WASTE

Element	Percent by Weight
Chromium	0.17
Cadmium	0.05
Copper	0.014
Zinc	0.81
Lead	0.22
Mercury	0.0001
Selenium	0.05
Nickel	0.02
Calcium	4.0*
Titanium	8.0*
Iron	1.0*
Silicon	2.0*
Sodium	3.0*
Aluminum	2.0*

* Semiquantitative results

20 percent originates from the material that settles out in the clarifier or collects on filters that follow the clarifier. The waste material is mostly calcium carbonate and other water insolubles. The sample was collected from both the saturator and the filter and clarifiers. They were mixed in the proportion of 80 percent saturator waste and 20 percent filter waste because the wastes from both locations are disposed of together in a holding area. The waste, as collected, was a moist, cream colored salt.

Analysis--

The quantitative, semiquantitative, and qualitative metal analyses were performed. The sample was dissolved in aqua regia and heated to

drive off the excess chlorine. A control sample and blank were prepared in a similar manner. Results are reported in Table 6.

TABLE 6. METAL ANALYSIS OF THE CHLORINE BRINE WASTE

Element	Percent by Weight
Mercury	0.004
Iron	0.3*
Copper	0.5*

* Approximate values. Sulfur, phosphorus, sodium, chlorine and calcium were present in substantial quantities.

The soluble chloride content of the waste (4.6 percent) was determined using the Mohr Method. This was done using a solution prepared by mixing 1 gram of waste with 20 milliliters of distilled water and stirring for 2 hours. The mixture was filtered before analysis.

The chlorine brine waste is quite alkaline. Addition of acid revealed that considerable carbonate was present. The carbonate content was found to 21 percent. Direct titration of the sludge was not possible, so alkalinity titrations were done on distilled water extracts. The titration was carried to pH 3.7. Alkalinity was found to be 1.04×10^{-5} equivalent of acid/gram of waste. A majority of the alkalinity appears due to bicarbonate and/or other bases that may have been only partially titrated. The titration curve is shown in Figure 9. The results using municipal landfill leachate are shown in Figure 10.

BATCH SOLUBILIZATION STUDIES

Introduction

Although the physical and chemical composition of the soil through which hazardous materials move has an important effect on their rate of movement, the solubility characteristics of wastes are also significant because they provide the source for mobile materials. The batch solubilization studies were designed to evaluate the concentration and rate of release of hazardous materials from the wastes under some conditions that relate directly to the selection and operation of disposal sites.

The solubilization of metals of interest from each of the wastes was studied in distilled water single batch extractions with pH adjusted to values of 5, 7, and 9 and was studied in serial batch extractions using

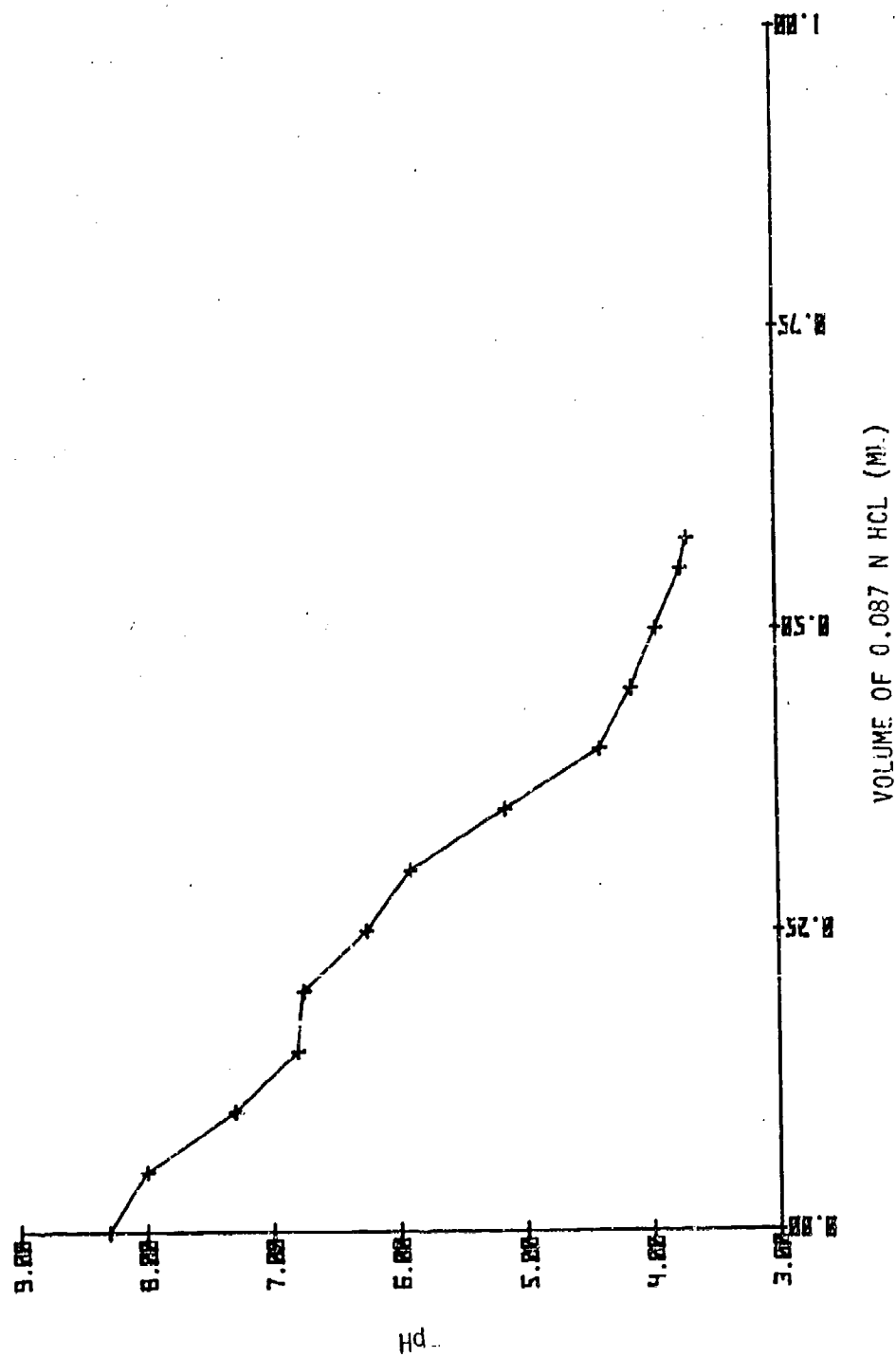


FIGURE 9: TITRATION CURVE FOR WATER EXTRACT OF CHLORINE PRODUCTION BRINE WASTE

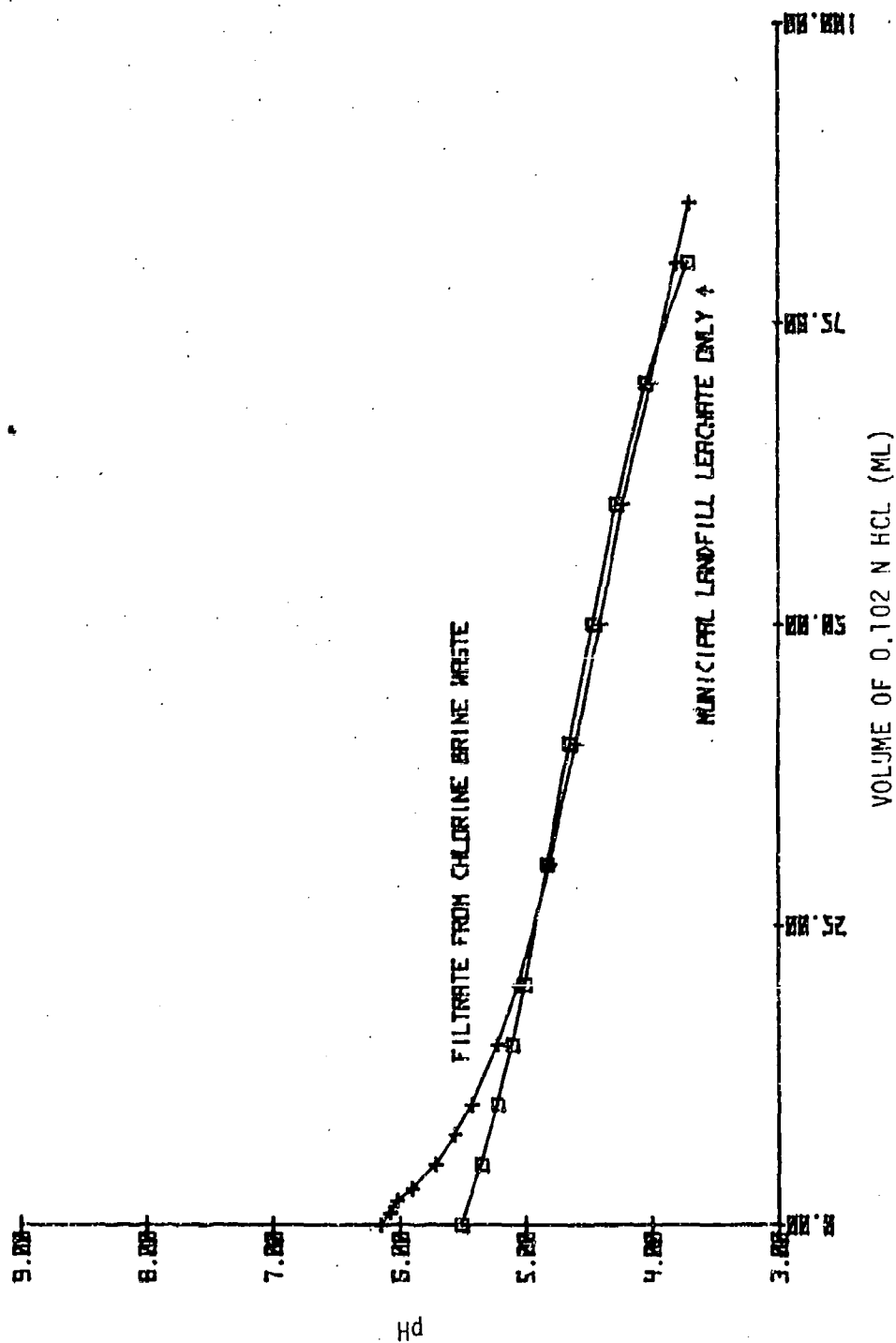


FIGURE 10: TITRATION CURVE FOR MUNICIPAL LANDFILL LEACHATE EXTRACT OF CHLORINE PRODUCTION BRINE WASTE AND MUNICIPAL LANDFILL LEACHATE ONLY

both distilled water and municipal landfill leachate as solvents. In the serial batch extractions the pH was not controlled externally but was allowed to fluctuate in response to interactions between the solvent and the waste. Distilled water was used to simulate the effect of rain-water or groundwater on solubilizing materials from the wastes. Municipal landfill leachate was used as the other solvent to simulate the effect of mixing industrial and municipal wastes in the same disposal site. It is known that during anaerobic decomposition of municipal wastes, significant amounts of organic acids are generated and released in the leachate; the single and serial batch municipal leachate studies were to determine if wastes in contact with such leachate released hazardous materials in greater amounts than when in contact with distilled water.

The variation in quality of leachates from various landfills and the continual change in quality of leachate from a single landfill are well known (9, 10); the range in characteristics is such that it is not possible to identify a "typical" landfill leachate. Additionally, landfill leachate is such a biologically and chemically active material that it is difficult to store for an extended period of time without significant changes in its chemical and physical properties. Consequently, the results of the landfill leachate studies (single batch extractions, serial batch extractions, and continuous flow columns) illustrate the type of interactions between wastes and landfill leachate but will probably not describe exactly the consequences of industrial waste disposal in a particular municipal landfill. Also, as discussed in Section 5, there is other evidence suggesting that hazardous materials solubilized from industrial wastes by landfill leachate may be adsorbed on the organic fraction of the municipal refuse and thus be prevented from leaving the landfill in substantial quantities.

Electroplating Waste

Single Batch pH Studies--

The waste-to-water ratios used in the pH solubility studies were 40 grams dry waste/400 milliliters water and 80 grams dry waste/400 milliliters water. In addition, two mixing times were used, 1 and 24 hours. The pH of each combination was adjusted to either 5 or 7 with concentrated nitric acid. The sample set at pH 9 was adjusted with 6 N sodium hydroxide. The initial (before the addition of alkali or acid) pH of the 40 grams waste/ 400 milliliters water was 7.2 while initial pH of the 80 grams waste/400 milliliters water was 7.3. The pH readings at 7 and 9 were quite stable and required little additional acid or base as the samples were stirred. However, samples set at pH 5 required repeated small additions of acid. After 24 hours, the 40 gram sample used 3.1 milliliters of concentrated nitric acid while the 80 gram sample required 5.7 milliliters. This indicates that much of the waste would be mobilized under acid conditions.

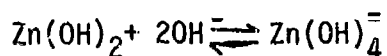
At the end of each mixing time, an aliquot of the sample was filtered and the filtrate was analyzed for heavy metals by AAS. The instrumental parameters used in the AAS analyses are presented at the end of this section. Analyses required for this waste sample were cadmium, chromium, copper and

zinc. In addition, considerable nickel was found in the waste sample. Therefore, the content of this metal was also measured quantitatively. Results are shown in Table 7.

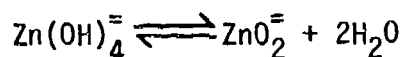
TABLE 7. SOLUBILIZATION OF METALS FROM ELECTROPLATING WASTE AT VARIOUS pH VALUES

Waste to 400 ml Water (grams)	Mixing Time (hours)	Metal content (mg/l)					
		pH	Cd	Cr	Cu	Ni	Zn
40	1	5	89	0.65	34	57	160
80	1	5	107	0.65	35	88	175
40	24	5	125	0.20	33	72	168
80	24	5	170	0.30	40	108	228
40	1	7	0.61	0.30	0.63	0.65	0.33
80	1	7	0.73	0.30	0.93	0.77	0.40
40	24	7	0.88	0.20	0.77	0.65	0.47
80	24	7	0.89	0.20	1.00	0.75	0.38
40	1	9	0.06	0.55	0.55	0.20	0.10
80	1	9	0.06	0.90	0.85	0.20	0.10
40	24	9	0.08	1.40	0.77	0.20	0.10
80	24	9	0.10	2.00	1.30	0.20	0.10

These results show that only small quantities of the metal are solubilized when neutral to alkaline conditions are maintained. However, except for chromium, considerable quantities of the metals are dissolved at pH 5. Chromium is different because chromium hydroxide is amphoteric (as is zinc). However, chromium and zinc belong to different chemical families. It is likely that zinc more readily forms complex ions than does chromium. In the presence of excess base, a complex zincate may form as follows:



Upon concentration or drying in the presence of base such as sodium hydroxide (all the waste samples were airdried before use in the laboratory), solid salts, such as Na_2ZnO_2 , crystallize out. This is represented by the following formula:



When the wastes are mixed with water, these complex salts are more soluble than is the hydroxide.

Conditions (alkaline) favoring immobilization of the other metals favor mobilization of the chromium. Chromium can be solubilized under

acid conditions, although to a lesser extent than the other metals. The lowest solubility was observed at neutrality.

Serial Batch Distilled Water Studies--

A second experiment was designed in which distilled water was mixed with the waste (20 grams waste/200 milliliters water). No pH adjustment was made. Samples were stirred for either 24 or 72 hours. At the end of each mixing period samples were filtered, and the filtrates were analyzed for metals by AAS. The residue was recovered and mixed with another 200 milliliters of water and the process was repeated. The 24 hour samples were discontinued after the fourth washing. It was doubtful that real differences in solubilization occurred between 24 and 72 hours. However, to insure maximum solubilization 72 hours were used in all subsequent experiments. The 72 hour samples were discontinued after seven washings. Results are shown in Table 8.

It appears that a fairly uniform solubilization occurs after three or four washings, as evidenced by the pH and conductivity. The heavy metal content was nearly uniform in all of the extracts. The results show that extraction for 24 hours compares favorably to the 72-hour extraction. In addition, the first extraction solubilized considerable quantities of ions other than the heavy metals, as indicated by the relatively higher conductivity. The total amount of ionic species extracted was reduced with each subsequent extraction until a nearly stable conductivity value was obtained at the fourth extraction. However, the heavy metal content showed little change. This indicates that near saturation was achieved in regard to the heavy metal content.

TABLE 8. SOLUBILIZATION OF METALS FROM ELECTROPLATING WASTE USING DISTILLED WATER (20 grams waste/200 milliliters water)

Extraction Number and Time	pH at Sampling	Specific Conductivity (Micromhos)	Metal Content (mg/l)				
			Cd	Cr	Cu	Ni	Zn
1st 24 hours	7.5	*	1.10	0.39	0.73	0.80	0.33
2nd 24 hours	6.8	*	0.84	0.18	0.11	0.55	0.33
3rd 24 hours	7.2	3120	0.93	0.15	0.10	0.50	0.32
4th 24 hours	6.9	*	1.00	0.32	0.19	0.57	0.38
1st 72 hours	7.4	6410	1.01	0.35	0.17	0.74	0.30
2nd 72 hours	6.2	*	0.62	0.07	0.16	0.83	0.27
3rd 72 hours	6.8	2600	0.93	0.18	0.08	0.56	0.31
4th 72 hours	6.9	2325	1.41	0.26	0.11	0.48	0.26
5th 72 hours	6.9	2270	1.13	0.43	0.06	0.47	0.26
6th 72 hours	7.1	2320	1.00	0.49	0.09	0.43	0.29
7th 72 hours	7.0	2160	0.80	0.56	0.05	0.42	0.25

*Not determined

This premise was tested further by increasing the weight of waste to volume of water. One kilogram of waste was mixed with 2000 milliliters of distilled water and the mixture was shaken for 72 hours (sampled at 24 and 72 hours). Samples were filtered; pH, conductivity and heavy-metals content were measured. The filtered waste was recovered and added to a fresh aliquot of water. Results are shown in Table 9.

TABLE 9. SOLUBILIZATION OF METALS FROM ELECTROPLATING WASTE USING DISTILLED WATER AT A WASTE TO WATER RATIO 1:2

Mixing Time (hours)	pH at Sampling	Specific Conductivity (Micromhos)	Metal Content (mg/l)				
			Cd	Cr	Cu	Ni	Zn
1st 24 hours	7.7	13,000	1.13	0.17	1.60	0.95	0.41
1st 72 hours	8.0	13,900	1.39	0.16	2.20	0.97	0.41
2nd 72 hours	7.3	5,600	1.10	0.05	0.25	0.87	0.43
3rd 72 hours	6.5	3,800	0.82	0.07	0.10	0.67	0.34

The results show very little change in heavy metal content, compared to results obtained from smaller ratios of weight of waste to volume of water. Conductivity doubled but did not increase fivefold (waste-to-water ratio was increased fivefold over the combination used previously). However, this indicated saturation was achieved in the higher waste-to-water ratio sample. It was also observed that a small increase in conductivity, pH, and the heavy metal content of Cd, Cu and Ni was obtained after 72 hours, compared to 24 hours. As a result, all subsequent samples were mixed for 72 hours. Waste used in this experiment was recovered and used in repeated washing studies at this increased waste-to-water ratio.

Serial Batch Landfill Leachate Studies--

The above experiments were repeated using municipal landfill leachate. Results are shown in Tables 10 and 11.

Specific conductivity of the leachate before application to the waste was 12,650 micromhos with pH of 5.8. Compared to Table 8, the results shown in Table 10 show that municipal landfill leachate solubilizes the heavy metals to a much greater degree than does distilled water.

A large increase in copper content was observed in the third and all subsequent extracts. However, pH exhibited no significant or dramatic change, as might be expected with such a large change in solubility of a metal constituent. However, municipal landfill leachate extract results cannot be interpreted simply in terms of pH or gross measurements such as specific conductivity. The leachate has remarkable base-consuming and metal solubilization ability, and the waste caused little effect upon pH

when it was mixed with leachate. After the second extraction of waste, much of the soluble material in the waste competing with copper for solubilization and/or complexing had been washed out and a large increase in copper solubilization was observed.

TABLE 10. SOLUBILIZATION OF METALS FROM ELECTROPLATING WASTE USING LANDFILL LEACHATE (20 grams waste/200 milliliters leachate)

Extract Number ¹	pH at Sampling	Specific Conductivity (Micromhos)	Metal Content (mg/l)				
			Cd	Cu	Cr	Ni	Zn
1st	6.0	*	80	4.5	0.53	35.0	15
2nd	*	*	75	3.6	0.46	17.5	63
3rd	*	*	77	203	0.31	15.5	71
4th	5.7	*	64	208	0.41	9.4	71
5th	*	*	46	127	0.72	6.5	47
6th	5.8	16,700	61	160	2.72	9.9	39
7th	*	*	35	90	0.51	2.7	33

¹ 72-hour extractions

* Not determined

TABLE 11. SOLUBILIZATION OF METALS FROM ELECTROPLATING WASTE USING LANDFILL LEACHATE AT A WASTE TO LEACHATE RATIO OF 1:2

Extract Number ¹	pH at Sampling	Specific Conductivity (Micromhos)	Metal Content (mg/l)				
			Cd	Cr	Cu	Ni	Zn
1st	7.2	17,500	32	0.12	43	18	15
2nd	6.6	18,700	73	0.35	127	27	36

¹ 72-hour extractions

Nickel-Cadmium Battery Production Waste

Single Batch pH Studies--

Solubilization studies were conducted using the waste-to-water ratios previously described. Initial pH, before addition of acid, was 11.2 for the 40 grams waste/400 milliliters water sample and 11.6 for the 80 grams waste/400 milliliters water sample. All samples required repeated addition of concentrated nitric acid to adjust pH to the desired values (pH 5, 7 and 9). The 40-gram sample adjusted to pH 9 required a total of 0.8 milliliter concentrated nitric acid, while the 80-gram sample required 1.4 milliliters. The 40-gram and 80-gram samples required 4.1 and 7.4 milliliters respectively at pH 7 and 7.6 and 14.7 milliliters respectively at pH 5. Whenever acid was added, considerable carbon dioxide was generated.

Samples were filtered at the end of each mixing period, and the filtrate was analyzed for nickel and cadmium. Results are shown in Table 12.

Results show that at pH 5 and 6 the waste is readily solubilized. Even at pH 9, considerable solubilization of the metals occurred.

Serial Batch Distilled Water Studies--

It is known that both nickel and cadmium are immobile at the high pH of the waste as it is generated from the battery production process. However, it is important to know how rapidly alkalinity can be leached from the waste to achieve solubilization of nickel and cadmium as alkalinity is reduced. Samples were cycled through a number of washes of distilled water as described in previous waste studies. Results listed in Table 13 show clearly that solubilization is initially limited by the high pH of the waste. After several washings, excess base is washed out of the waste, conductivity of the extracts is greatly reduced, and the pH of the extracts is lowered to below 9. Thereafter, heavy metals are more readily solubilized.

Serial Batch Landfill Leachate Studies--

This experiment was repeated with municipal landfill leachate. Results, given in Table 14, show that municipal landfill leachate solubilizes nickel and cadmium much more than does water. Of great importance is the ability of leachate to neutralize much of the alkalinity of the waste even during the first washing. This is also shown in the titration curve (Figure 4) prepared from an aliquot of the first washing.

An experiment in which the weight of waste to volume of water was increased to 1,000 grams waste to 2,000 milliliters water was conducted using both distilled water and municipal landfill leachate. This was done to assure saturation of ionic species in the waste extract and to simulate high waste to water combinations as might be expected in field disposal situations. After samples had equilibrated for 72 hours, they were filtered, the filtrate was analyzed, and remaining waste mixed with another aliquot of water (the sample used with landfill leachate was lost after the first washing and this part of the characterization study was discontinued). The results are shown in Table 15.

These results suggest that saturation had been achieved at the 1:2 ratio. The weight of waste to water was increased fivefold over that

TABLE 12. SOLUBILIZATION OF NICKEL AND CADMIUM FROM NICKEL-CADMIUM BATTERY WASTE AT THREE pH VALUES

Gram Waste to 400 ml Water	Mixing Time (hours)	pH	Heavy Metal Content (mg/l)	
			Ni	Cd
40	1	5	1,400	29,250
80	1	5	4,200	47,500
40	24	5	3,300	49,000
80	24	5	6,200	86,200
40	48	5	3,900	51,200
80	48	5	6,700	86,000
40	1	7	430	15,500
80	1	7	600	20,625
40	24	7	580	29,940
80	24	7	1,400	44,650
40	48	7	790	28,200
80	48	7	1,150	36,200
40	1	9	1.70	55.5
80	1	9	0.85	25.7
40	24	9	4.35	234
80	24	9	2.45	128
40	48	9	1.40	61.5
80	48	9	1.30	68.5

TABLE 13. SOLUBILIZATION OF METALS FROM NICKEL-CADMIUM BATTERY WASTE USING DISTILLED WATER (20 grams waste/200 milliliters water)

Extraction Number and Time	pH at Sampling	Specific Conductivity (micromhos)	Metal Content (mg/l)	
			Ni	Cd
1st 24 hours	11.7	*	0.20	0.30
2nd 24 hours	10.3	*	0.20	0.07
3rd 24 hours	9.9	*	0.20	0.17
4th 24 hours	9.4	140	0.20	1.06
5th 24 hours	8.9	21	0.48	4.60
1st 72 hours	11.8	10,400	0.20	0.10
2nd 72 hours	10.7	*	0.20	0.27
3rd 72 hours	9.5	950	0.20	0.07
4th 72 hours	9.1	37	0.29	1.47
5th 72 hours	8.9	21	0.48	4.60
6th 72 hours	8.9	21	0.87	4.90
7th 72 hours	9.0	23	0.22	1.64

*Not determined

TABLE 14. SOLUBILIZATION OF METALS FROM NICKEL-CADMIUM BATTERY WASTE USING LANDFILL LEACHATE (20 grams waste/200 milliliters leachate)

Extraction ^a	pH at Sampling	Specific Conductivity (micromhos)	Metal Content (mg/l)	
			Ni	Cd
1st	8.1	*	34	700
2nd	*	*	24	3,100
3rd	8.0	*	29	3,540
4th	6.4	*	78	1,690
5th	*	*	138	924
6th	6.0	14,500 ^b	163	720
7th	5.8	15,150 ^c	55	775

*Not determined

^aEach extracted for 72 hours

^bConductivity of the leachate before mixing with the waste was 12,600 micromhos, pH = 5.6

^cConductivity of leachate before mixing with the waste was 14,900 micromhos, pH = 5.8

used to obtain the information shown in Table 13. However, conductivity increased only threefold. Metal content increased slightly as compared to the lower ratio in Table 13. These results suggest that excess base and other unreacted soluble materials were washed from the waste during the first extraction steps. However, the concentration of the metals of concern were quite similar regardless of the waste to water ratio used.

When municipal landfill leachate was used, the metal content was much higher (Table 14) than obtained from the distilled water extraction (Table 13).

Additional nickel-cadmium battery production waste had to be obtained because the amount available in the first collection was insufficient for completion of the study. Although the additional waste was collected from the same location, there are some differences between the two wastes. The differences are discussed below.

Quantitative analysis for nickel and cadmium in the second waste sample were conducted. The sample was prepared by dissolving 1 gram of waste in 25 milliliters of aqua regia, and the mixture was diluted to 1 liter with water. Metal analysis was performed by AAS and the following results were obtained: nickel (percent by weight) 11; cadmium (percent by weight) 52. These figures compare closely with those obtained from the original nickel-cadmium waste sample (10.1 and 51.0, respectively).

TABLE 15. SOLUBILIZATION OF METALS FROM NICKEL-CADMIUM BATTERY PRODUCTION WASTE AT A WASTE TO SOLVENT RATIO OF 1:2

Extraction Number and Time	Solvent	pH at Sampling	Specific Conductivity (micromhos)	Metal Content (mg/l)	
				Ni	Cd
1st 24 hours	Water	12.1	34,500	0.34	0.41
1st 72 hours	Water	12.1	34,500	0.33	0.50
2nd 72 hours	Water	11.6	8,690	2.00	0.84
1st 24 hours	Leachate	11.7	32,260 ^a	7.90	3.60

^aConductivity of the leachate before mixing with the waste was 14,900 micromhos.

An experiment in which waste to water ratio was increased to 500 grams waste to 1,000 milliliters water was conducted using distilled water. After samples had been shaken for 72 hours, they were filtered and the filtrate was analyzed. The results shown in Table 16 are comparable to the values obtained from the first waste sample (Table 15).

TABLE 16. SOLUBILIZATION OF METALS FROM NICKEL-CADMIUM BATTERY PRODUCTION WASTE AT A WASTE TO SOLVENT RATIO OF 1:2

Extraction 72-Hour	Solvent	pH at Sampling	Specific Conductivity (micromhos)	Metal Content (mg/l)	
				Ni	Cd
1st Sample	Water	12.2	34,500	0.34	0.41
2nd Sample	Water	9.1	43,500	0.70	7.20

The basicity of the second sample was found to be much less than that of the first sample. In addition, considerably more material was solubilized in the second sample as shown by the specific conductivity.

Inorganic Pigment Waste

Single Batch pH Studies--

Solubility of heavy metals in the pigment waste was determined at three pH values (5, 7 and 9). Because of the pH of the waste-water mixture (approximately 8), it was recognized that the pH would have to be adjusted with acid to maintain the desired values of 5 and 7 and with base to maintain pH 9. Concentrated nitric acid and 4 N sodium hydroxide were used.

Only one waste to water combination and mixing time were used with the pH study (20 grams of waste/200 milliliters of water). The initial pH obtained from this combination, before addition of acid or base, was 8.3. The sample adjusted to pH 5 required approximately 7 milliliters of concentrated nitric acid. The sample was stirred for 72 hours. During this time 1 additional milliliter of concentrated nitric acid was required. The pH 7 sample required 2 milliliters of acid while the pH 9 sample required 1.5 milliliters of base. At the end of 72 hours, all three samples were filtered and the heavy metal content of the filtrates was measured by AAS. Results are shown in Table 17.

TABLE 17: SOLUBILIZATION OF METALS FROM INORGANIC PIGMENT WASTE AT VARIOUS pH VALUES

Grams Waste to 200 ml Water	Mixing Time (hours)	pH	Metal Content (mg/l)							
			Be	Cu	Cr	Cd	Ni	Zn	Hg	Pb
20	72	5	<0.01	2.40	2.5	37.00	10.00	15.00	0.018	0.017
20	72	7	<0.01	<0.02	2.1	0.06	0.08	0.02	<0.005	0.220
20	72	9	<0.01	0.07	36.0	0.01	0.14	<0.01	0.012	11.500

As indicated, except for chromium and lead, the metals are more soluble under acid conditions than under neutral or basic conditions. These results, as expected, emphasize that the waste should not be disposed of under acid conditions. Unfortunately, basic conditions solubilize chromium and lead, while nearly immobilizing the other metals. These factors may limit options for disposal of waste.

Serial Batch Distilled Water Studies--

Repeated extraction studies were conducted using distilled water and the experimental conditions previously described. Results are shown in Table 18.

Except for chromium, only very small quantities of heavy metals are solubilized from the pigment waste by distilled water. These results compare favorably with results shown in Table 17 at pH 7 and 9.

Serial Batch Landfill Leachate Studies--

The experiment outlined above was repeated using municipal landfill leachate. Results are shown in Table 19.

The results demonstrate again that many of the heavy metals are solubilized much more with landfill leachate than with water. The pH is changed very little by the waste and conductance is significantly higher than in the water experiments (even after subtraction of the "as-is" leachate conductance from the value obtained from the waste-leachate combination). It is interesting to note that pigment waste appears to

TABLE 18. SOLUBILIZATION OF METALS FROM INORGANIC PIGMENT WASTE USING DISTILLED WATER (20 grams waste/200 milliliters water)

Extraction ^a	pH	Specific Conductivity (micromhos)	Metal Content (mg/%)							
			Be	Cu	Cr	Cd	Ni	Hg	Zn	Pb
1st Sample	8.3	*	<0.01	<0.02	7.2	0.05	0.09	0.0015	<0.01	0.17
2nd Sample	*	*	<0.01	<0.02	6.1	0.03	0.05	0.0560	0.03	0.20
3rd Sample	8.2	*	<0.01	<0.02	7.6	0.06	0.05	0.0006	0.15	0.10
4th Sample	7.5	1,220	<0.01	<0.02	5.4	<0.02	0.11	<0.0002	0.04	0.07
5th Sample	7.2	712	<0.01	<0.02	5.9	<0.02	0.08	<0.0002	<0.01	<0.05
6th Sample	6.9	503	<0.01	<0.02	4.8	<0.02	<0.05	<0.0002	<0.01	<0.05
7th Sample	6.7	385	<0.01	<0.02	3.6	<0.02	<0.05	<0.0002	<0.01	<0.05

^aEach extracted for 72 hours

*Not determined

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TABLE 19. SOLUBILIZATION OF METALS FROM INORGANIC PIGMENT WASTE USING LANDFILL LEACHATE (20 grams waste/200 milliliters leachate)

Extraction ^a	pH	Specific Conductivity (micromhos)	Metal Content (mg/l)							
			Be	Cu	Cr	Cd	Ni	Hg	Zn	Pb
1st Sample	*	*	<0.01	1.80	3.5	6.0	2.1	0.4200	<1	6.4
2nd Sample	*	*	<0.01	0.27	3.1	15.7	4.6	<0.0002	<1	14.0
3rd Sample	5.7	*	<0.01	0.12	0.9	12.3	5.5	<0.0002	14	22.0
4th Sample	5.8	*	<0.01	0.12	1.4	9.3	4.2	<0.0002	46	32.0
5th Sample	*	*	<0.01	0.04	1.1	7.8	4.3	0.0010	<1	32.0
6th Sample	5.8	14,280 ^b	<0.01	<0.02	1.5	6.6	1.8	0.0002	<1	33.0
7th Sample	5.8	15,630 ^c	<0.01	0.10	0.8	4.9	1.2	<0.0002	<1	28.0

*Not determined

^aEach extracted for 72 hours

^bConductivity of leachate was 12,650 micromhos.

^cConductivity of leachate was 14,900 micromhos.

TABLE 20. SOLUBILIZATION OF METALS FROM INORGANIC PIGMENT WASTE USING WASTE TO SOLVENT RATIO OF 1:2

Extraction ^a	Solvent	pH at Sampling	Specific Conductivity (micromhos)	Metal Content (mg/L)						
				Cu	Cr	Cd	Ni	Hg	Zn	Pb
1st Sample	Water	8.1	4,610	0.15	3.40	0.08	0.50	0.005	<0.02	0.25
2nd Sample	Water	*	*	<0.04	3.50	0.04	0.30	*	<0.02	0.40
1st Sample	Leachate	7.6	14,300	3.20	0.67	0.42	0.95	0.010	0.08	0.96
2nd Sample	Leachate	*	*	6.10	0.30	0.33	0.80	*	0.02	0.39

^aExtracted for 72 hours

*Not determined

remove zinc from the municipal landfill leachate. The zinc content in the original leachate was found to be 60 microgram/milliliter. The resultant extract of pigment contained much less.

The waste-to-water ratio was increased to 1:2 using the weights and volumes previously mentioned, both with water and with municipal landfill leachate. Results are shown in Table 20.

Solubilization of heavy metals from the pigment waste was less than expected. Even at pH 5, the metal content of the extract was less than extracts from other wastes treated in the same manner, perhaps because of the organic flocculating polymer that was added to the wastewater at the plant to promote precipitation of metals. The polymer may occlude the metals making them unavailable for extraction.

Water Base Paint Waste

Single Batch pH Studies--

Solubility of heavy metals in the paint waste was determined at pH 5, 7 and 9. The original pH of the waste/water mixture (20 grams of waste/200 milliliters of water) was 8.6. Nitric acid was added to adjust the pH to 5 and 7. The pH 5 sample required an additional 3.5 milliliters of acid during 24 hours of stirring. A second sample was prepared at the same pH and stirred for 72 hours. This sample required 4.1 milliliters of acid. The pH readings were fairly stable after the initial addition of acid and only small volumes of additional acid were required while stirring. The two samples adjusted to pH 7 required 0.04 and 0.08 milliliter of acid to maintain the desired pH during the 24 and 72 hours of stirring. The samples adjusted to pH 9 required additions of 0.4 and 1.0 milliliter of 4.0 N sodium hydroxide. The results are shown in Table 21.

TABLE 21. SOLUBILIZATION OF METALS FROM PAINT WASTE AT THREE pH VALUES

Grams Waste to 200 ml Water	Mixing Time (hours)	pH	Metal Content (mg/l)						
			Be	Cu	Cr	Cd	Ni	Hg	Zn
20	24	5	<0.01	0.18	0.15	0.22	0.51	28	313
20	72	5	<0.01	0.25	0.15	0.24	1.70	38	297
20	24	7	<0.01	<0.02	0.51	0.07	<0.05	-- ^a	0.48
20	72	7	<0.01	<0.02	<0.02	0.06	0.38	0.0027	1.64
20	24	9	<0.01	<0.02	0.52	0.04	<0.05	-- ^a	0.08
20	72	9	<0.01	<0.02	0.53	0.02	<0.05	0.0013	0.03

^aNot determined

As with other wastes, disposal of this waste under acid conditions would solubilize heavy metals (except for chromium) much more than if disposed of under neutral or alkaline conditions.

A sequential washing study was conducted with water and municipal landfill leachate as described before. Results are shown in Tables 22 and 23.

Serial Batch Distilled Water Studies--

Water base paint waste appears to be very insoluble in water (refer to Table 22). Conductance was surprisingly low even after the first and second extracts. Concentrations of most of the heavy metals were less than the detection limit of the analysis. These findings would indicate that waste in neutral to alkaline environments would present little immediate hazard to water supplies. Insolubility of the heavy metals is probably caused largely by the paint base and the flocculating polymer used to promote precipitation. How fast the polymer degrades in the waste environment is unknown. It is conceivable that very little material will be leached from the waste until the polymer is degraded.

Serial Batch Landfill Leachate Studies--

Municipal landfill leachate extracted significantly larger quantities of some of the heavy metals than did water. Conductivity is higher than that obtained on distilled water extracts. The pH was nearly equal to that obtained from leachate alone. This further demonstrates the high buffering capacity of municipal landfill leachate.

Experiments at increased waste-to-solvent ratios were conducted using distilled water and municipal landfill leachate as previously described. Results are shown in Table 24.

The data shown in Table 24 suggest that extracts from the waste were saturated (refer to Tables 21 and 22 for comparison) because there was no significant increase in metal content when the higher ratio was used. Municipal landfill leachate again extracted considerably more heavy metals than did distilled water.

Chlorine Production Brine Waste

Single Batch pH Studies--

The solubility of metals was determined at pH 5, 7 and 9. The pH of each waste-to-solvent combination was adjusted to either 5 or 7 with concentrated nitric acid. Samples were stirred for 1 or 24 hours. The initial pH of the samples before addition of acid was 9.1 for both waste-to-water combinations. The sample adjusted to pH 9 was stable and required no additional acid. However, the pH 5 and 7 samples required repeated additions of concentrated nitric acid. The 40 grams waste/400 milliliters water set at pH 7 required 0.4 milliliter of acid, while the 80 grams waste/400 milliliters water sample required 0.67 milliliter. Some evolution of carbon dioxide was observed. The 40 and 80 gram samples, set at pH 5,

TABLE 22. SOLUBILIZATION OF METALS FROM WATER BASE PAINT WASTE USING DISTILLED WATER (20 grams waste/200 milliliters water)

Extract Number and Time	pH at Sampling	Specific Conductivity (micromhos)	Metal Content (mg/l)							
			Be	Cu	Cr	Cd	Ni	Zn	Hg	Pb
1st 24 hrs	8.0	998	<0.01	0.02	0.52	0.44	<0.05	0.08	0.0004	<0.05
1st 72 hrs	7.6	1,105	<0.01	<0.02	0.32	0.13	<0.05	0.13	0.0004	<0.05
2nd 72 hrs	*	*	<0.01	<0.02	0.14	<0.02	<0.05	0.10	0.0011	<0.05
3rd 72 hrs	*	*	<0.01	<0.02	0.15	<0.02	<0.05	0.06	0.0015	<0.05
4th 72 hrs	8.0	*	<0.01	<0.02	<0.05	0.16	<0.05	1.60	0.0011	<0.05
5th 72 hrs	6.9	345	<0.01	<0.02	<0.05	<0.02	<0.05	<0.01	0.0008	<0.05
6th 72 hrs	6.9	343	<0.01	<0.02	0.05	<0.02	<0.05	0.22	0.0008	<0.05
7th 72 hrs	6.8	370	<0.01	<0.02	<0.05	<0.02	<0.05	0.44	0.0007	<0.05

*Not determined

TABLE 23. SOLUBILIZATION OF METALS FROM WATER BASE PAINT USING LANDFILL LEACHATE (20 grams waste/200 milliliters leachate)

Extract Number	pH at Sampling	Conductivity (micromhos)	Metal Content (mg/ℓ)							
			Be	Cu	Cr	Cd	Ni	Zn	Hg	Pb
1st sample	5.8	*	<0.01	0.24	<0.02	11.50	0.75	135	0.014	0.95
2nd sample	*	*	<0.01	0.08	<0.02	5.60	0.55	101	0.001	1.70
3rd sample	5.9	*	<0.01	0.21	0.06	0.61	2.40	14	0.003	2.70
4th sample	5.8	*	<0.01	0.25	0.03	0.34	2.80	73	0.011	6.00
5th sample	*	*	<0.01	0.08	0.02	0.18	2.80	20	0.008	4.40
6th sample	5.8	14,500 ^b	<0.01	<0.02	0.26	0.12	0.80	27	0.010	5.90
7th sample	5.8	15,870 ^c	<0.01	0.04	0.23	0.11	0.77	12	0.011	2.30

*Not determined

^aExtracted for 72 hours

^bConductivity of leachate was 12,659 micromhos, pH 5.6

^cConductivity of leachate was 14,900 micromhos, pH 5.8

TABLE 24. SOLUBILIZATION OF METALS FROM WATER BASE PAINT WASTE USING A WASTE TO SOLVENT RATIO OF 1:2

Extraction ^a	Solvent	pH at Sampling	Conductivity (micromhos)	Metal Content (mg/ℓ)						
				Cd	Cr	Cu	Ni	Zn	Hg	Pb
1st Sample	Water	7.1	2,600	<0.02	0.22	0.26	0.11	0.13	0.013	<0.05
2nd Sample	Water	6.9	1,630	<0.02	<0.04	<0.02	<0.05	<0.01	*	<0.05
1st Sample	Leachate	6.8	14,090	1.10	0.15	0.10	0.58	202.00	0.032	1.30
2nd Sample	Leachate	6.9	15,150	0.06	0.09	3.09	0.54	310.00	*	3.50

*Not determined

^aExtracted for 72 hours

required considerably more acid (17.9 and 29.8 milliliters, respectively). Even after 24 hours, the pH reading was not completely stabilized. A large amount of carbon dioxide was evolved.

Samples were filtered at the end of each mixing period, and the filtrates were analyzed for mercury using the flameless mercury attachment with AAS. Results are shown in Table 25.

TABLE 25. SOLUBILIZATION OF MERCURY FROM CHLORINE BRINE WASTE AT THREE pH VALUES

Grams Waste to 400 ml Water	Mixing Time (hours)	pH	Mercury Content (mg/l)
40	1	5	0.0090
80	1	5	0.0090
40	24	5	0.0090
80	24	5	0.0090
40	1	7	0.0013
80	1	7	0.0013
40	24	7	0.0018
80	24	7	0.0043
40	1	9	0.0008
80	1	9	0.0009
40	24	9	0.0017
80	24	9	0.0029

Serial Batch Distilled Water Studies--

Additional experiments were conducted using 20 grams of waste/200 milliliters of water. No adjustment of pH was made. Samples were extracted for 24 and 72 hours. At the end of each extraction period, the pH was measured, the sample was filtered, and the mercury content was measured. The waste residue was then combined with another aliquot of distilled water and mixed for 72 additional hours. This was repeated through seven washings. Results are shown in Table 26.

Serial Batch Landfill Leachate Studies--

The above experiment was repeated using municipal landfill leachate as solvent. Results are given in Table 27.

The results shown in Table 27 indicate an initial increase in solubilization of mercury when municipal landfill leachate is used. However, solubilization drops off in subsequent washings to a nearly non-detectable level. The amount of mercury solubilized from the waste by both municipal landfill leachate and water is far below what is available, based upon information shown in Table 6. The waste contains approximately 40 parts per million of mercury. Only a small fraction of this quantity was solubilized in these studies.

TABLE 26. SOLUBILIZATION OF MERCURY FROM CHLORINE PRODUCTION BRINE WASTE USING DISTILLED WATER (20 grams waste/200 milliliters water)

Extraction Number and Time	pH at Sampling	Specific Conductivity (micromhos)	Mercury Content (mg/l)
1st 24 hours	9.1	*	0.0009
1st 72 hours	8.8	20,000	0.0013
2nd 72 hours	*	3,400	0.0003
3rd 72 hours	*	2,700	<0.0002
4th 72 hours	*	2,400	<0.0002
5th 72 hours	*	2,300	0.0002
6th 72 hours	*	2,400	<0.0002
7th 72 hours	*	2,200	<0.0002

*Not determined

TABLE 27. SOLUBILIZATION OF MERCURY FROM CHLORINE PRODUCTION BRINE WASTE USING LANDFILL LEACHATE (20 grams waste/200 milliliters leachate)

Extraction Number and Time	pH at Sampling	Specific Conductivity (micromhos)	Mercury Content (mg/l)
1st 72 hours	6.2	*	0.0130
2nd 72 hours	*	*	0.0002
3rd 72 hours	6.5	*	0.0010
4th 72 hours	6.3	*	0.0014
5th 72 hours	*	*	0.0012
6th 72 hours	5.9	15,000 ^a	0.0009
7th 72 hours	6.1	16,700 ^b	0.0002

*Not determined

^aConductivity of leachate was 12,700 micromhos/centimeter, pH 5.6

^bConductivity of leachate was 14,900 micromhos/centimeter, pH 5.8

COLUMN STUDIES OF WASTE SOLUBILIZATION

Preparation of Columns

At the completion of the serial batch solubilization studies, fresh samples of the wastes were packed into columns for use in studies of metal migration through soil. The wastes and the soils were packed in separate columns to allow tapping off samples of waste column leachates

(Figure 11). The columns were made from 37 millimeter I.D. glass tubing with an 8-millimeter tip on the bottom. A piece of glass wool was placed over the bottom hole and covered with washed quartz sand. One hundred grams of the waste were then packed into the column to a depth of 10 to 13 centimeters, depending upon the waste. The waste was covered with 1 centimeter of sand and a thin layer of glass wool and then fitted with a stopper containing a three-way stopcock which allowed either sampling the waste leachate after it passed from the waste column or directing it through an upflow path into the soil column above. An upflow arrangement was used to maintain saturation, to minimize channeling, and to permit better flow control at the desired flow rate of 0.5 to 1.5 soil pore volumes per day, which is equivalent to 3.1 surface centimeters of liquid applied per day (based upon 40 milliliter pore volume).

The ease with which water or municipal landfill leachate penetrated the waste column varied greatly between wastes. At the 7 foot head pressure used for these experiments, the solvents penetrated the dense electroplating waste very slowly. The very dense nickel-cadmium battery waste had to be mixed in equal proportions with sand before a useful flow could be obtained. The eluting solvents passed through the pigment, paint and chlorine brine readily.

Twelve columns of each waste were prepared as described above. Three were connected to columns of Davidson soil and three to Kalkaska soil columns and were leached with distilled water. The remaining six waste columns were also connected to Davidson and Kalkaska soil columns but they were leached with municipal landfill leachate. The characteristics of these soils are discussed in Section 5. After the start of leaching, the waste column leachate at the three-way stopcock in Figure 11 was sampled periodically and analyzed for metal content to provide information on the concentration of each metal being presented to the soil columns. The concentration of metals remaining in the waste leachate after passage through the soil columns will be discussed in Section 5.

Data Reduction

Instead of using soil pore volume as the independent variable in plotting the results, the output concentration was plotted as a function of cumulative milliliters/gram through the columns. This allowed pooling the six sets of waste column data, the triplicates of each of two soils. Only one graph was required and the pooled values provided a better estimate of the concentration of each metal presented to the soil columns. These plots also gave enough points that regression curves could be fitted instead of drawing lines point-to-point. Least squares regression analysis was used to derive equations for the relationships. This technique provided a basis for subtracting blank curves, for obtaining the area under curves, which corresponds to the total weight of metal eluted, and for evaluating the effect of selected variables. Polynomial regression curves of degree 6 usually fit the data best as judged by the R-square value (a goodness-of-fit parameter that can be interpreted as the fraction of the

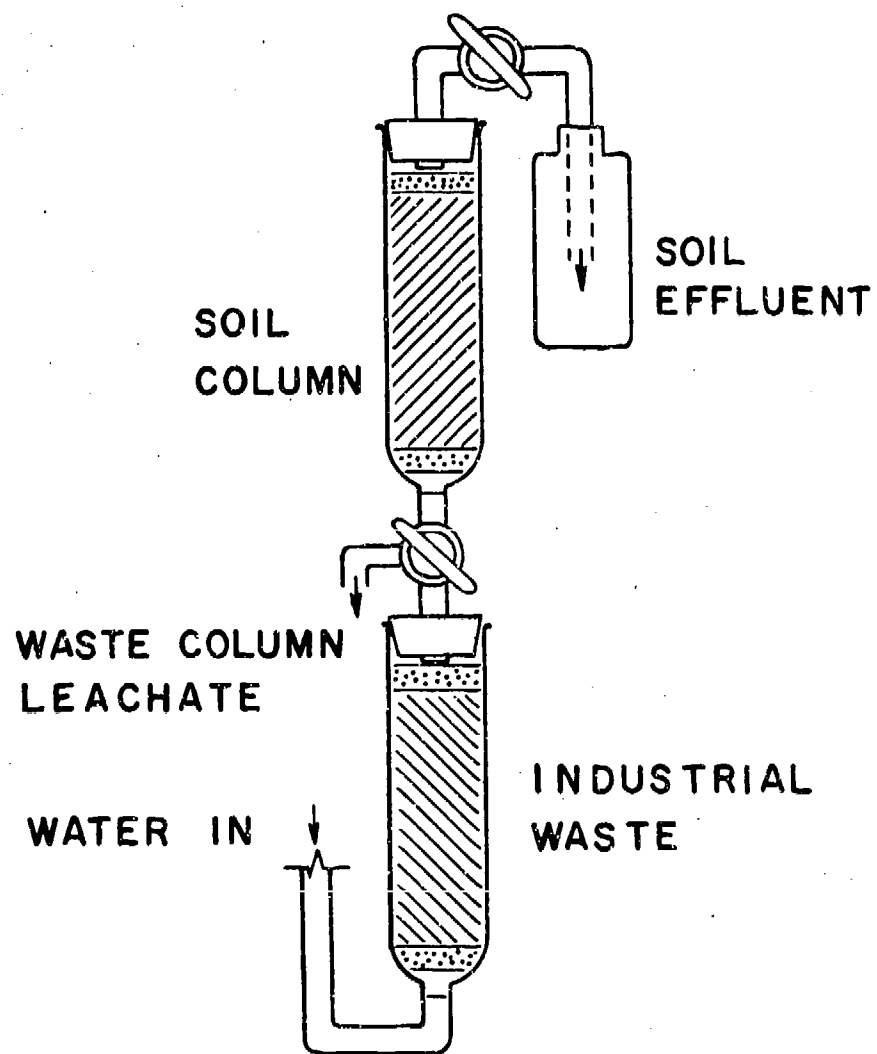


FIGURE 11: COLUMN CONFIGURATION

data adequately represented by the line; a value above 0.3 is considered acceptable). Although the R-square values usually indicate an excellent fit statistically, humping in some regions visually appears excessive, an idiosyncrasy of polynomial curves, so a lower degree polynomial was chosen when judged preferable on the basis of appearance (the R-square value of the lower degree polynomial equation usually differed only slightly).

Residuals (the deviations from the fitted curves) were examined by plotting them in several different ways (11). This indicated that a least square analysis is valid, that the variance is adequately constant so transformation of the data is not needed, that there is no systematic departure of the experimental data from the calculated value, and that the waste column is not flow rate dependent although the soil column output concentration can be. Residuals have proved to be an important diagnostic tool, particularly for identifying outliers. Over two-thirds of the curves had no data points identified as outlying values; most of the rest had only one or two outliers.

Electroplating Waste

Distilled Water--

The combined results from six electroplating waste columns leached with water are shown in Figures 12 through 15. Only cadmium, copper, nickel, and zinc were plotted because chromium was not detected in the waste leachate. The number shown at each data point identifies the waste column. The coefficients and constant for the polynomial equation are also given in each plot as is the R-square value.

The four metals eluted similarly from the waste columns. A moderately high concentration of each metal was found in the initial waste leachate samples. The elution of cadmium and copper illustrates this observation. The initial average cadmium value was approximately 2.1 micrograms/milliliter followed by a rapid decrease in subsequent samples to a nearly uniform concentration of 0.8 to 1.0 microgram/milliliter. The average concentration of copper was initially 2.6 micrograms/milliliter followed by a decrease of 0.5 microgram/milliliter and a gradual increase to 0.6 to 0.8 microgram/milliliter. Nickel and zinc behaved very similarly.

Plots of the pH and specific conductance values found in each waste-leachate sample support the above findings. Figure 16 is a plot of the pH values and Figure 17 is a plot of the specific conductances. The pH decreased only slightly during the leaching, indicating that little excess basicity or other soluble species existed in the waste sample whose elution from the sample would significantly alter the pH.

This is shown further by the specific conductance data. An initial specific conductance of approximately 3,000 micromhos was found in the first samples of waste leachate. This decreased to approximately 2,000 followed by a slight increase. This is very similar to the way the metals eluted from the waste.

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 2.127158488
 COEFF X = -1.038471397
 COEFF X² = 0.341769883
 COEFF X³ = -0.054132458
 COEFF X⁴ = 4.34012E-03
 COEFF X⁵ = -1.70021E-04
 COEFF X⁶ = 2.56475E-05

R² = 0.334877074

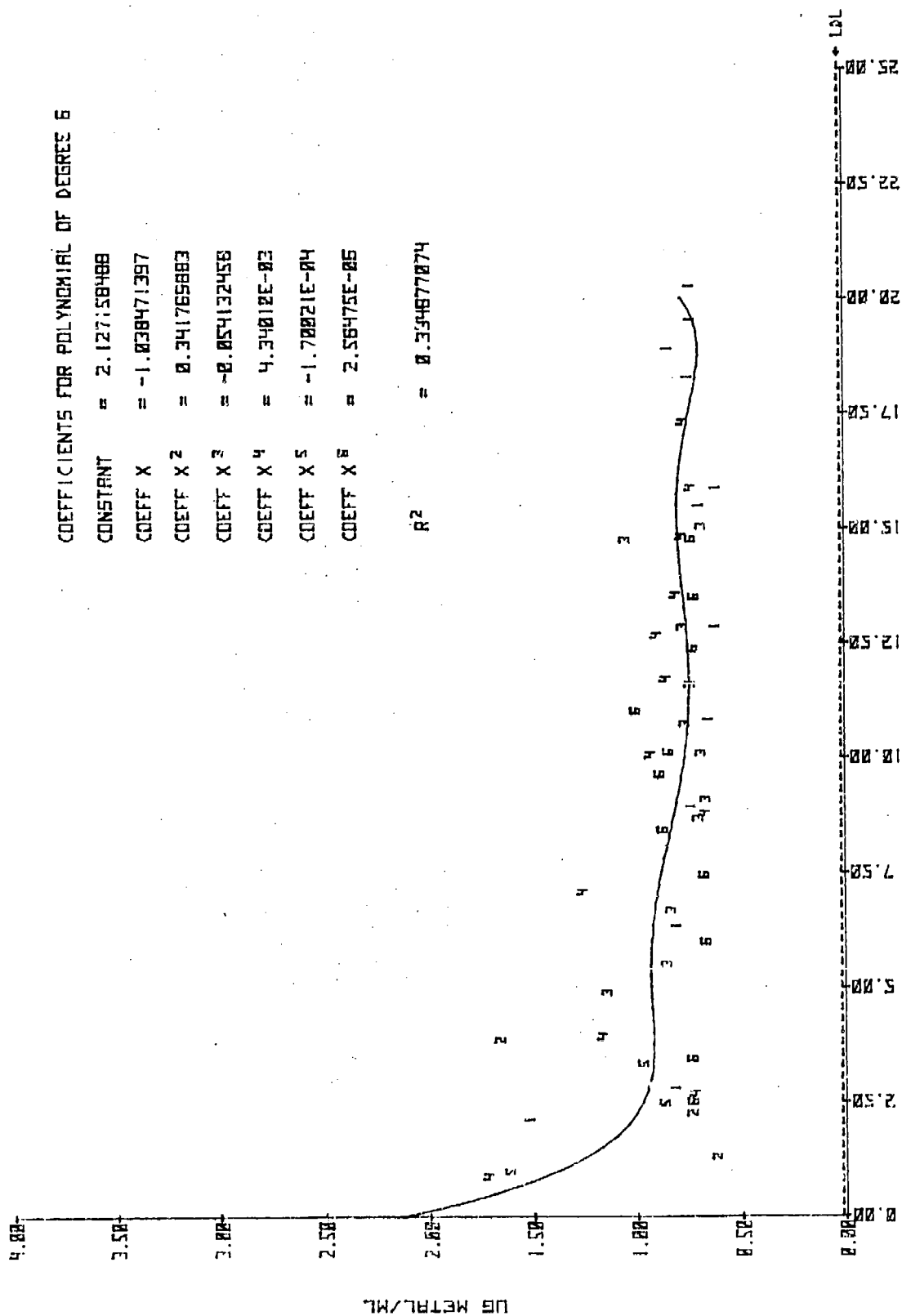
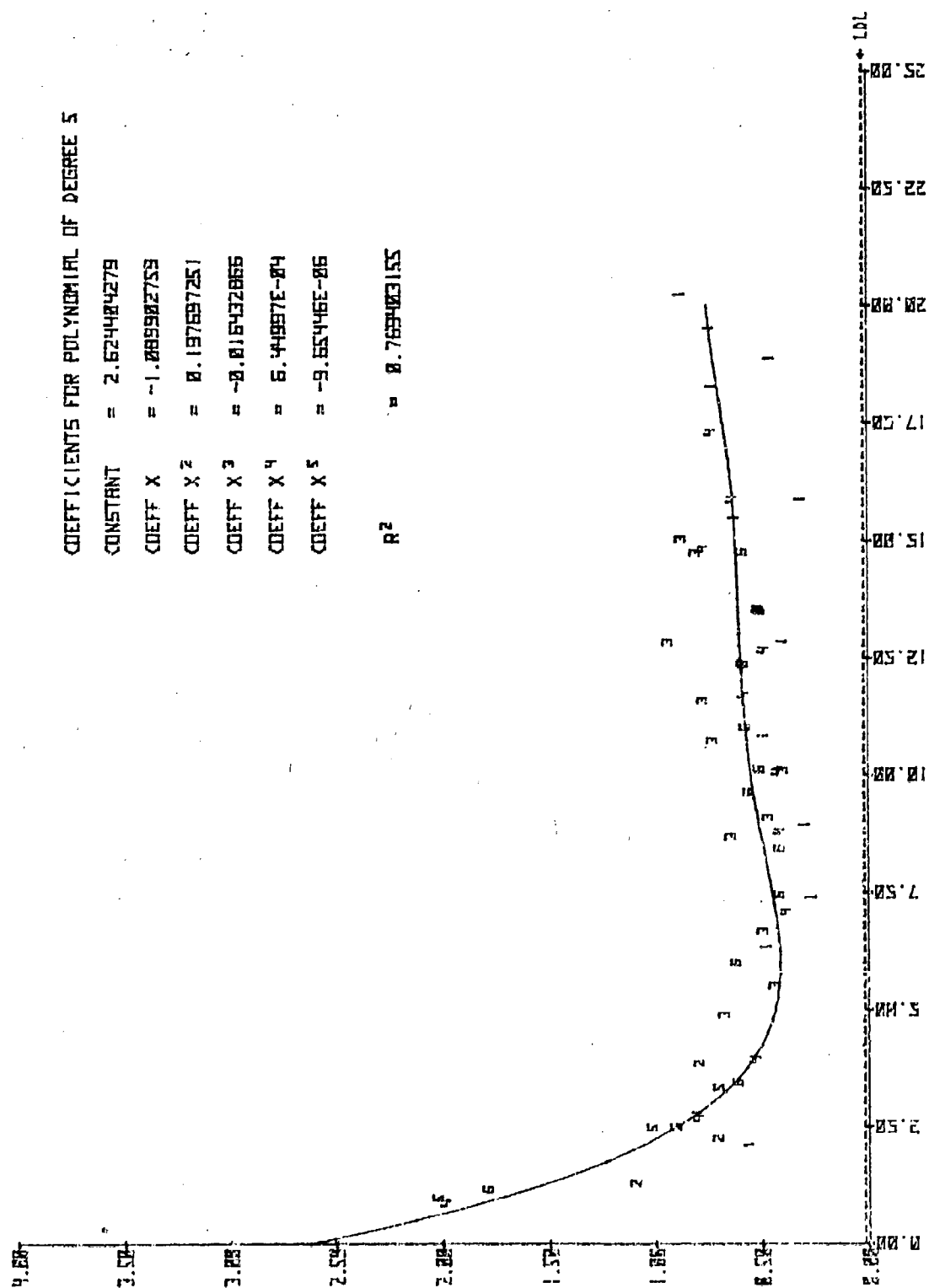


FIGURE 12: CADMIUM LEACHED FROM ELECTROPLATING WASTE BY WATER

U1 METRL/ML



CUM VOLUME (ML/EM)

FIGURE 13: COPPER LEACHED FROM ELECTROPLATING WASTE BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 2.624484279
 COEFF X = -1.089902759
 COEFF X² = 0.197697251
 COEFF X³ = -0.016432866
 COEFF X⁴ = 6.44997E-04
 COEFF X⁵ = -9.65446E-06

R² = 0.763403155

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 2.445250231
 COEFF X = -1.383890258
 COEFF X² = 0.379586873
 COEFF X³ = -0.050624474
 COEFF X⁴ = 3.51441E-03
 COEFF X⁵ = -1.22494E-04
 COEFF X⁶ = 1.69654E-06
 R² = 0.984935225

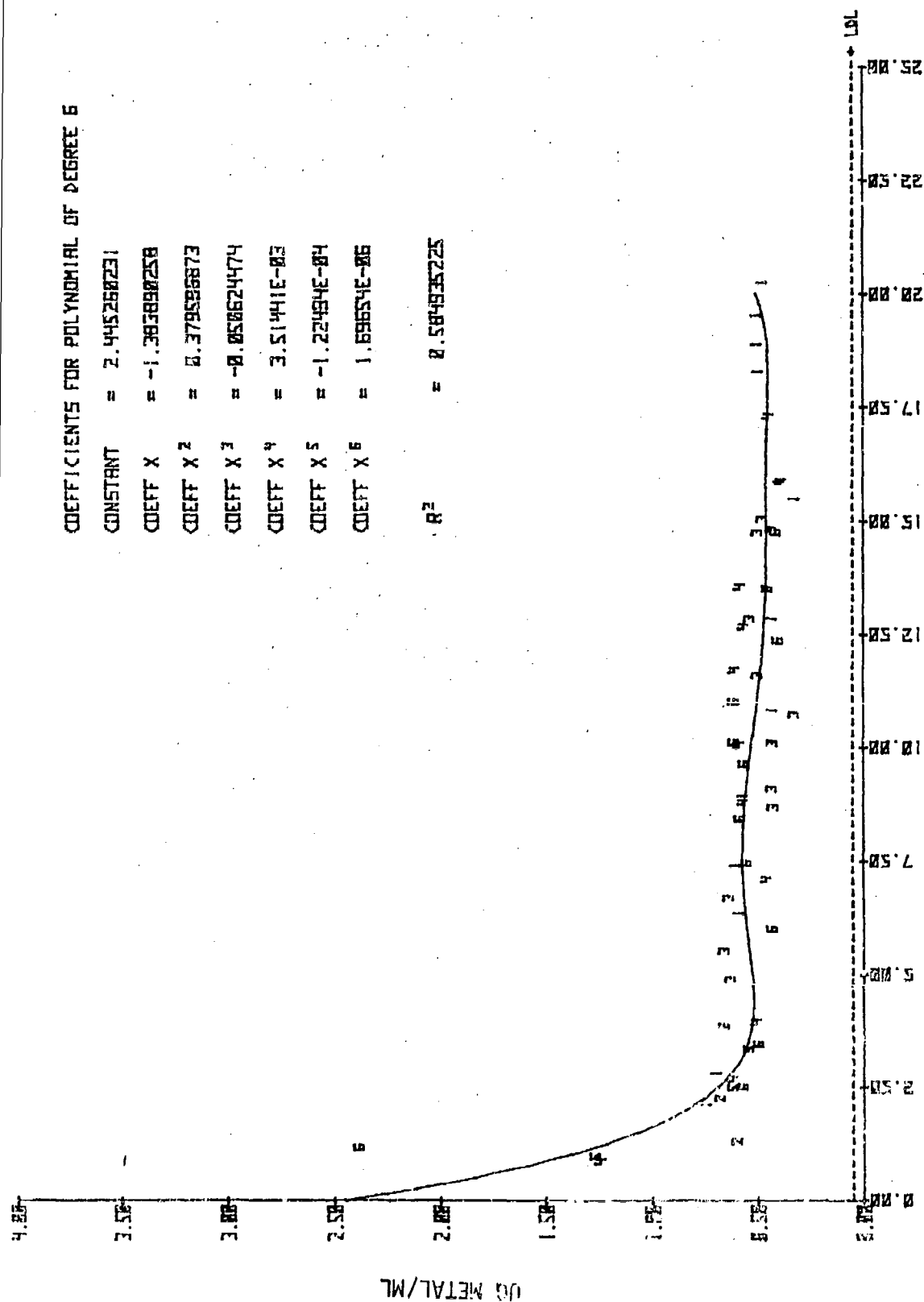


FIGURE 14: NICKEL LEACHED FROM ELECTROPLATING WASTE BY WATER

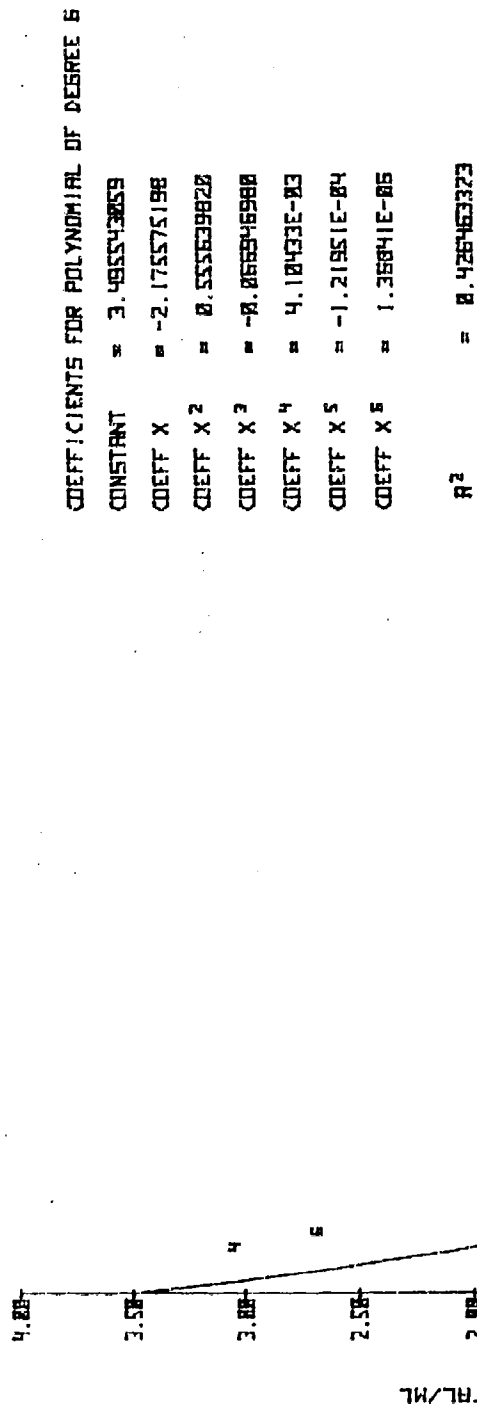


FIGURE 15: ZINC LEACHED FROM ELECTROPLATING WASTE BY WATER

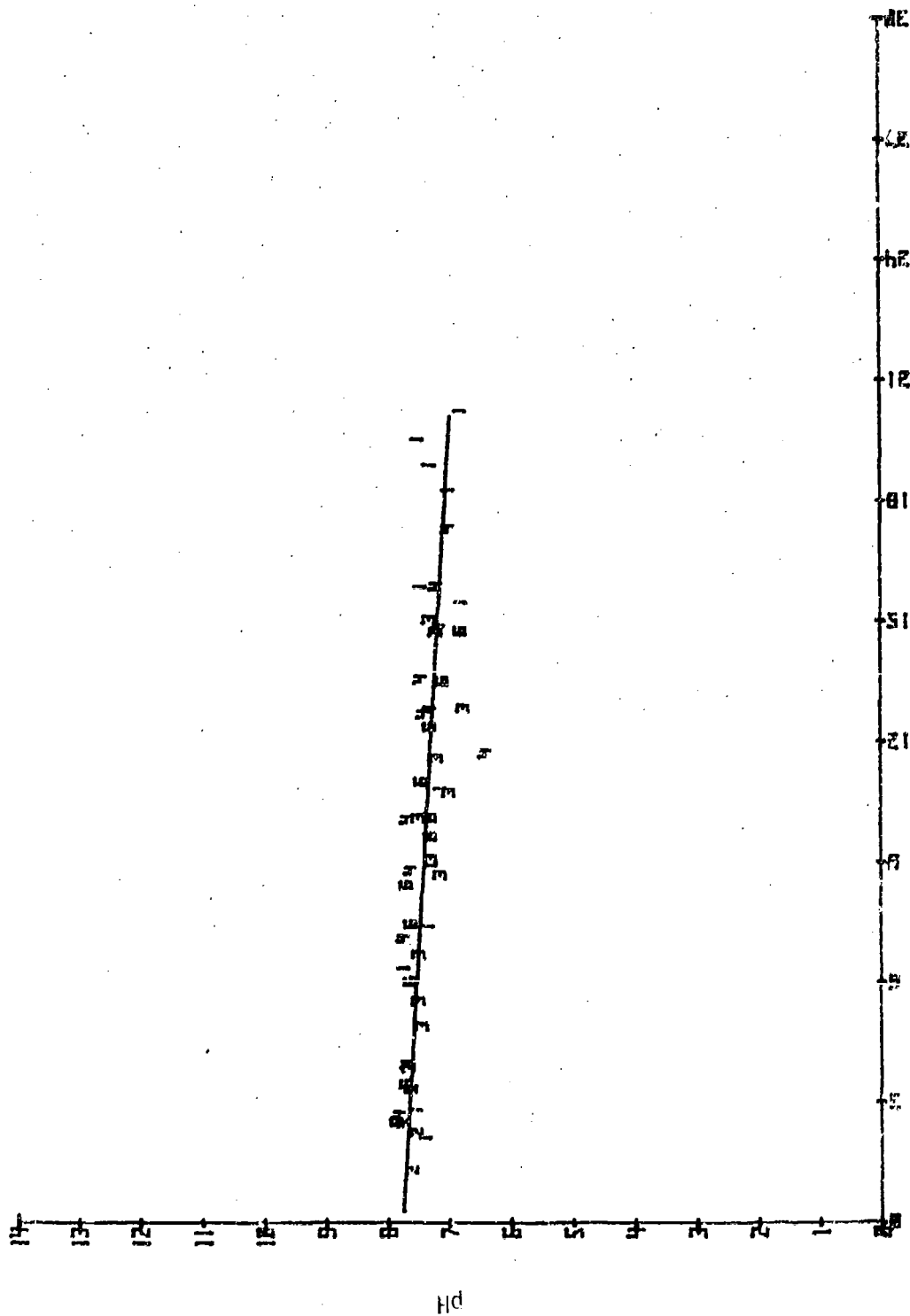


FIGURE 16: pH OF SOLUTION LEACHED FROM ELECTROPLATING WASTE
BY WATER

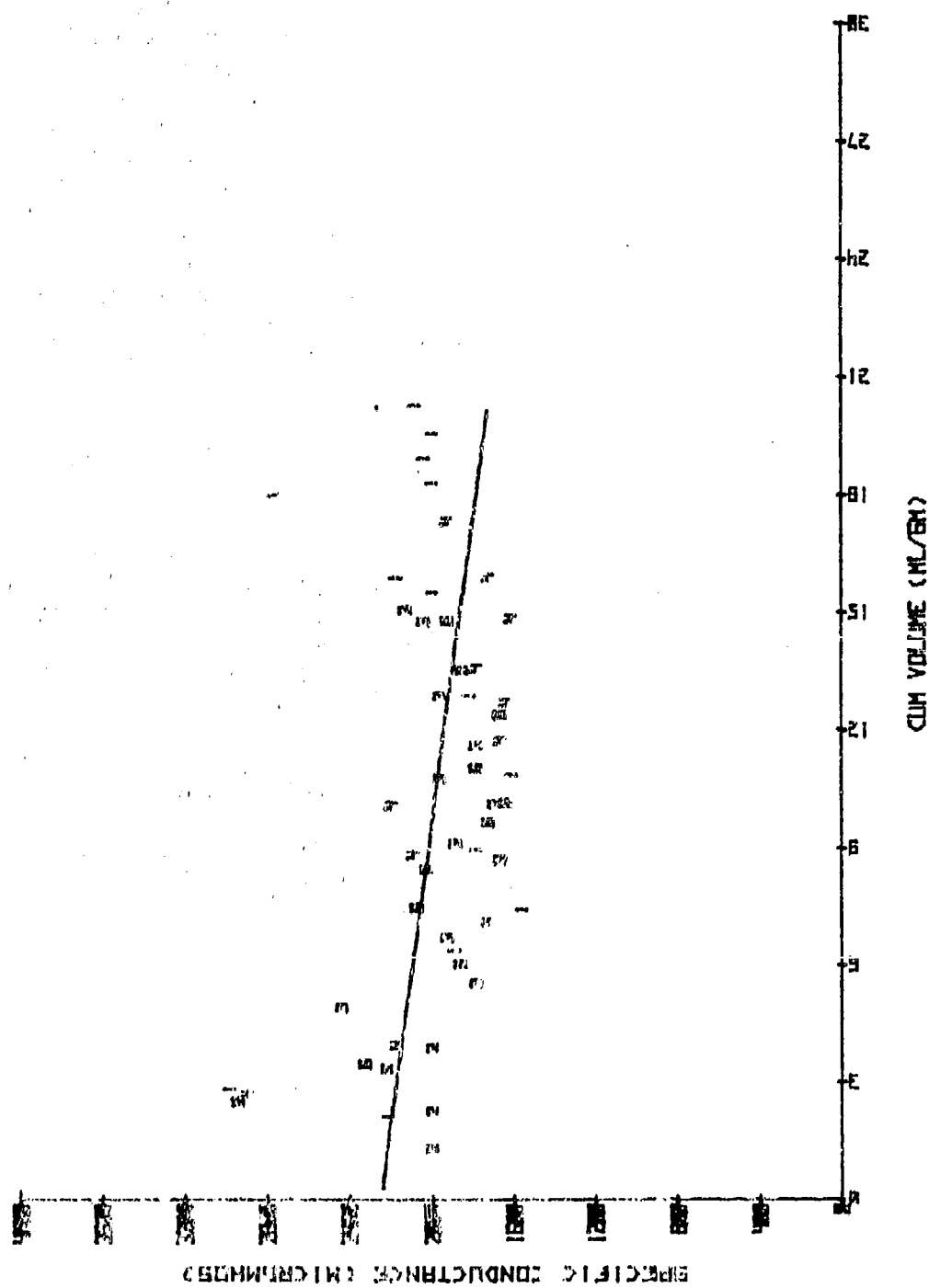


FIGURE 17: CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING WASTE BY WATER

The concentrations of the metals in the waste leachate were higher, except for cadmium, than is possible if they are present in the waste as hydroxides (see Table 1), especially during the initial leaching of the waste columns. The metals are probably present as some salt other than hydroxide or as a more soluble complex ion; e.g., zinc may be present as a tetrahydroxyzincate ion which is more soluble than zinc hydroxide. As the leaching continued and most of the more soluble species were removed from the waste, the concentration of each metal decreased; except for copper, the concentration of the metals reached or approached the solubility possible for the hydroxide salts of each.

Cadmium was leached from the electroplating waste to the largest extent during the time allotted for this experiment (18.8 micrograms/gram of waste) and therefore presents the greatest potential hazard. It was followed by copper (14.7 micrograms/gram), zinc (14.4 micrograms/gram), and nickel (12.7 micrograms/gram).

There are presently no standards for hazardous substances in waste leachates; drinking water standards (13) are cited as a point of reference. This does not constitute a recommendation that these standards should be applied to waste leachates and it does not imply that the true environmental impact of waste leachates can be estimated by comparison with drinking water standards. Furthermore, the concentrations observed in laboratory leaching experiments may not closely represent what would occur in the field under varying environmental and waste disposal conditions, and does not take into account further dilution in aquifers and attenuation by soils before entering drinking water. Soil column effluent data is present later in this report and in a paper by Wentinik and Etzel (14).

Cadmium was 100 to 200 times above the drinking water standard. Copper exceeded the standards by 2 to 2.5 times during the early part of the leaching but ultimately decreased below the drinking water standard. Zinc never exceeded the drinking water level. A level has not been set for nickel. The drinking water standards for some elements are shown in Table 28.

TABLE 28. DRINKING WATER STANDARDS FOR METALS OF INTEREST (13)

Element	Concentration ($\mu\text{g/ml}$)
Cd	0.01
Cr	0.05
Cu	1.00
Pb	0.05
Zn	5.00

In addition to recognizing that the concentration of some metals in the electroplating waste leachate exceeded the safe drinking water standard, attention must also be given to the total weight leached. For example, the total cadmium leached from the waste was 18.1 micrograms/gram of waste over the time of the experiment shown in Figure 12. This is a very small fraction of what is potentially available (see Table 2). As a result, cadmium from this waste could leach for many months because in the 2 or 3 months of continuous leaching in these experiments, approximately 1/400th of the potentially available cadmium was leached from the waste and was still leaching when the experiment was terminated.

Landfill Leachate--

The plots of each metal found in the waste leachate from the six combined waste columns leached with municipal landfill leachate are shown in Figures 18 through 21. In addition, a small amount of chromium was also leached from the electroplating waste. This was not plotted because it appeared in the waste samples sporadically.

The concentrations of cadmium, copper, nickel and zinc found in the first samples when municipal landfill leachate was used as the leaching solvent were similar to the concentrations found in the waste leachate when water was used as the leaching solvent. Cadmium was initially leached from the waste at a concentration of 2.2 micrograms/milliliter of landfill leachate but increased later to an average of 6.0 micrograms/milliliter (Figure 18). This is an increase of approximately sixfold over the water results during the later phase of the leaching. Copper initially appeared at 1.9 micrograms/milliliter and increased to an average of 3 to 3.2 micrograms/milliliter (Figure 19). This is also an increase of five- to sixfold over the concentration of copper leached from the waste by water. Nickel was leached at an initial concentration of 1.2 micrograms/milliliter and increased only slightly to a concentration of approximately 1.5 micrograms/milliliter (Figure 20). This is an increase of approximately threefold. Zinc was initially found to average 3.3 micrograms/milliliter (Figure 21). The concentration remained at this level or decreased slightly during the latter leaching phase.

The pH of the waste leachate samples, shown in Figure 22, were slightly lower when the electroplating waste was leached with municipal landfill leachate as compared to the water leaching experiments. However, the specific conductance values from the municipal landfill leachate studies, shown in Figure 23, are much greater than in the water studies. Even if the average initial conductance value of the "as-is" municipal landfill leachate (approximately 6,000 micromhos) is subtracted from the waste leachate readings, the conductances of the samples are substantially greater than the conductances obtained from the water leaching samples.

Both cadmium and copper concentrations exceeded the drinking water level in the waste leachate. The total cadmium eluted from the electroplating waste by landfill leachate was 9.9 micrograms/gram of waste. This is less than the total cadmium eluted from the waste by water.

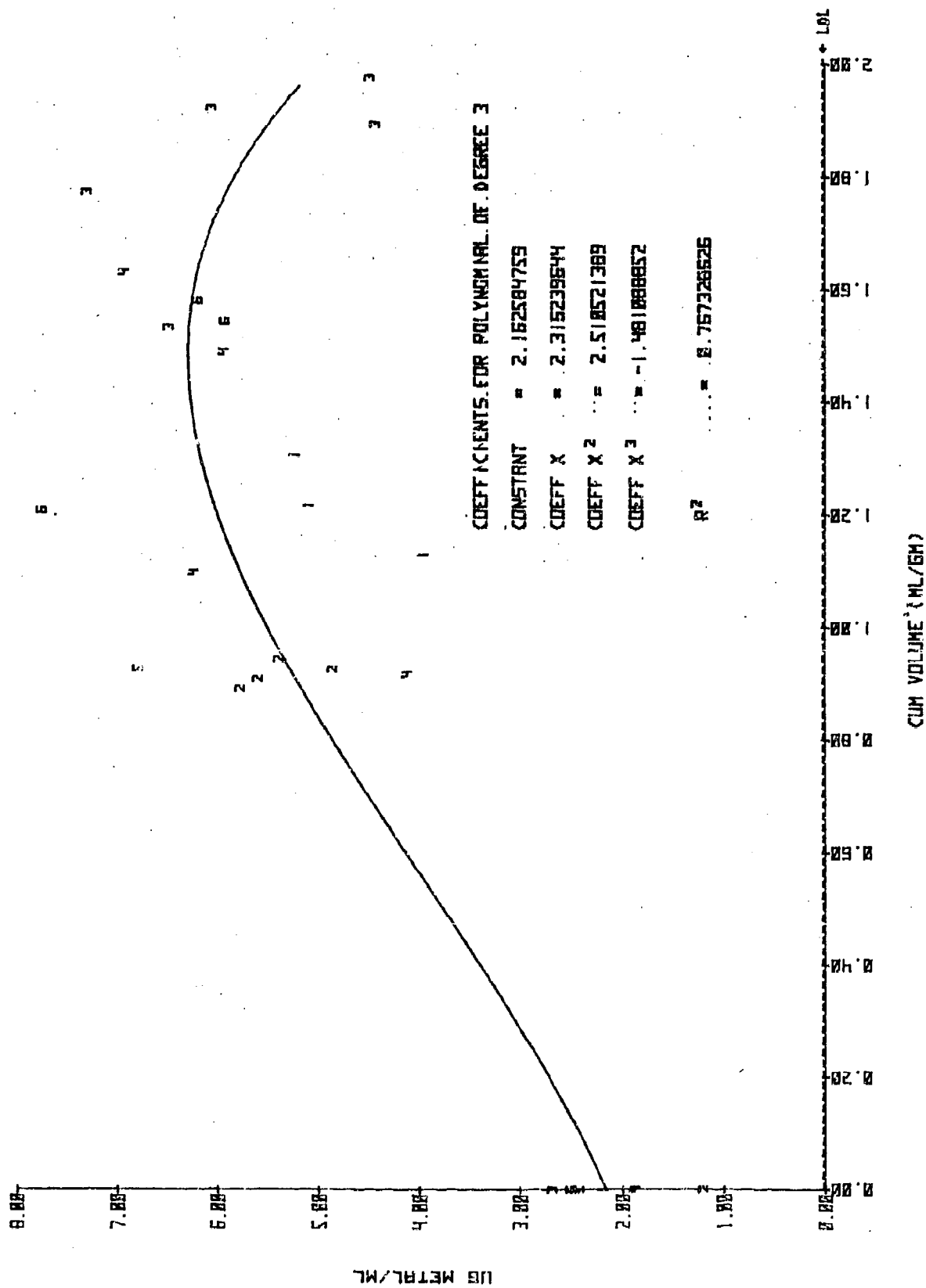


FIGURE 18: CADMIUM LEACHED FROM ELECTROPLATING WASTE BY LANDFILL LEACHATE

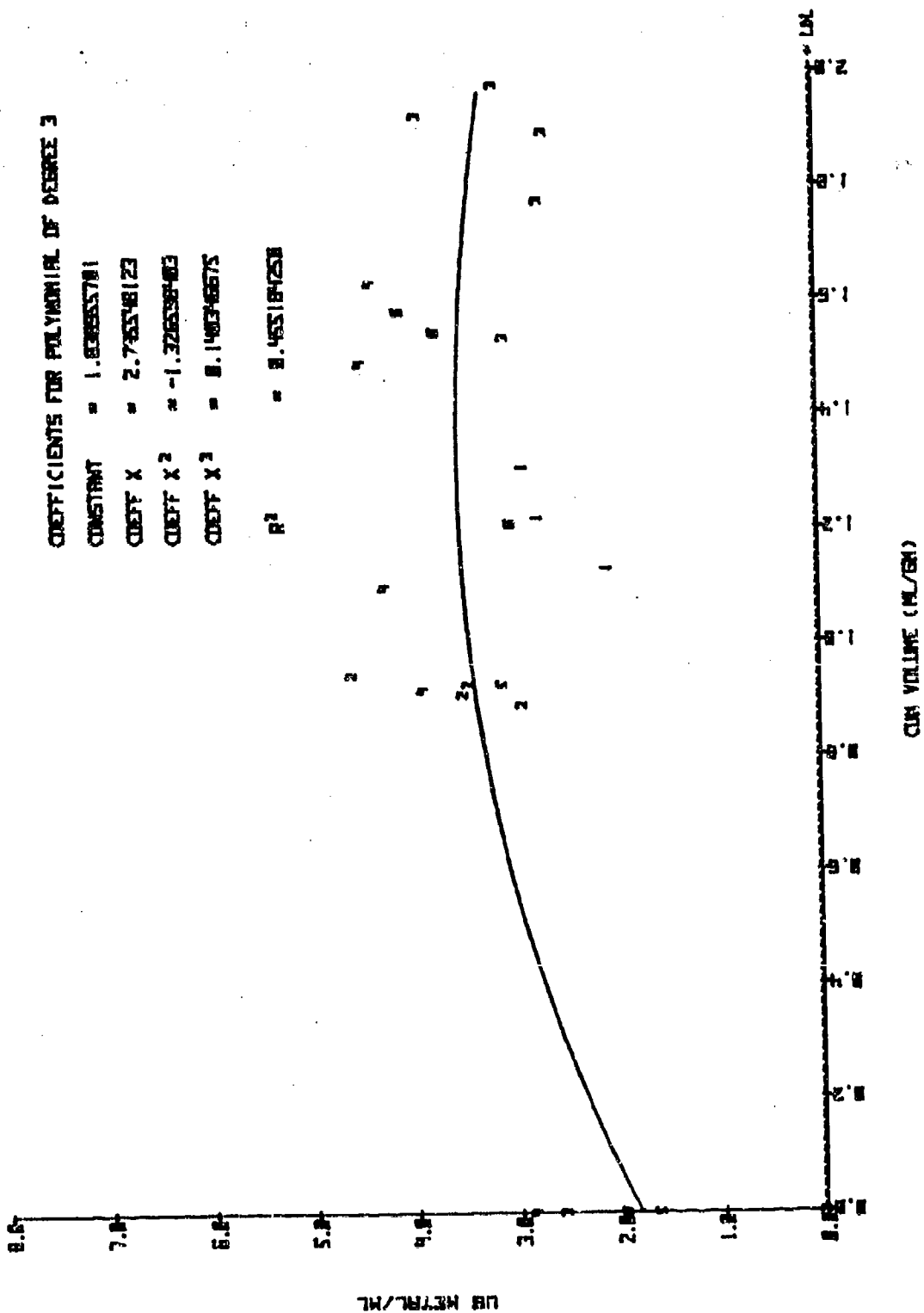
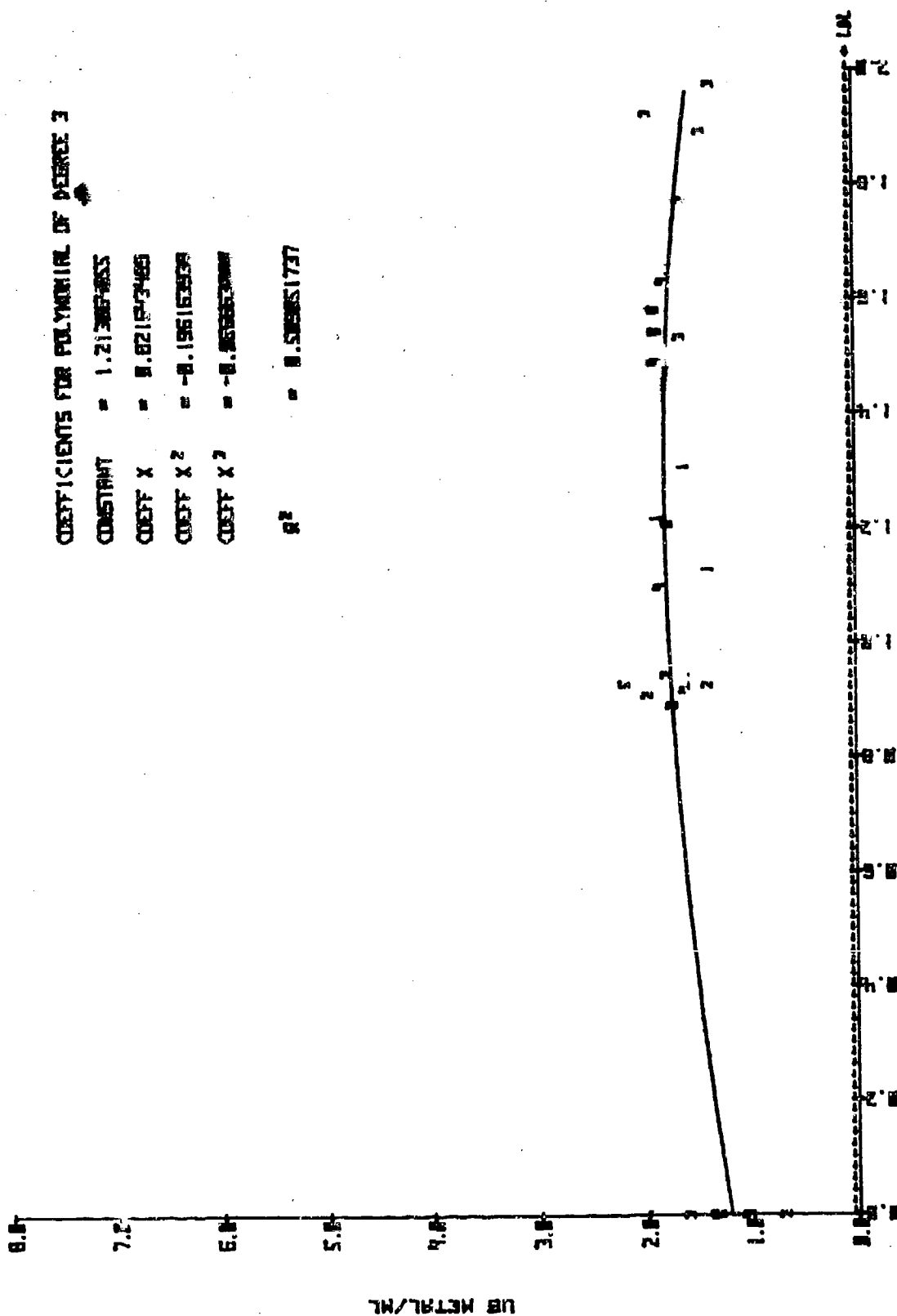


FIGURE 19: COPPER LEACHED FROM ELECTROPLATING WASTE BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

CONSTANT = 1.2130674855

COEFF X = 0.021573485

COEFF X² = -0.196153339

COEFF X³ = -0.05555555555

R² = 0.99951737

CM VOLUME (ML/CM)

FIGURE 20: NICKEL LEACHED FROM ELECTROPLATING WASTE BY LANDFILL LEACHATE.

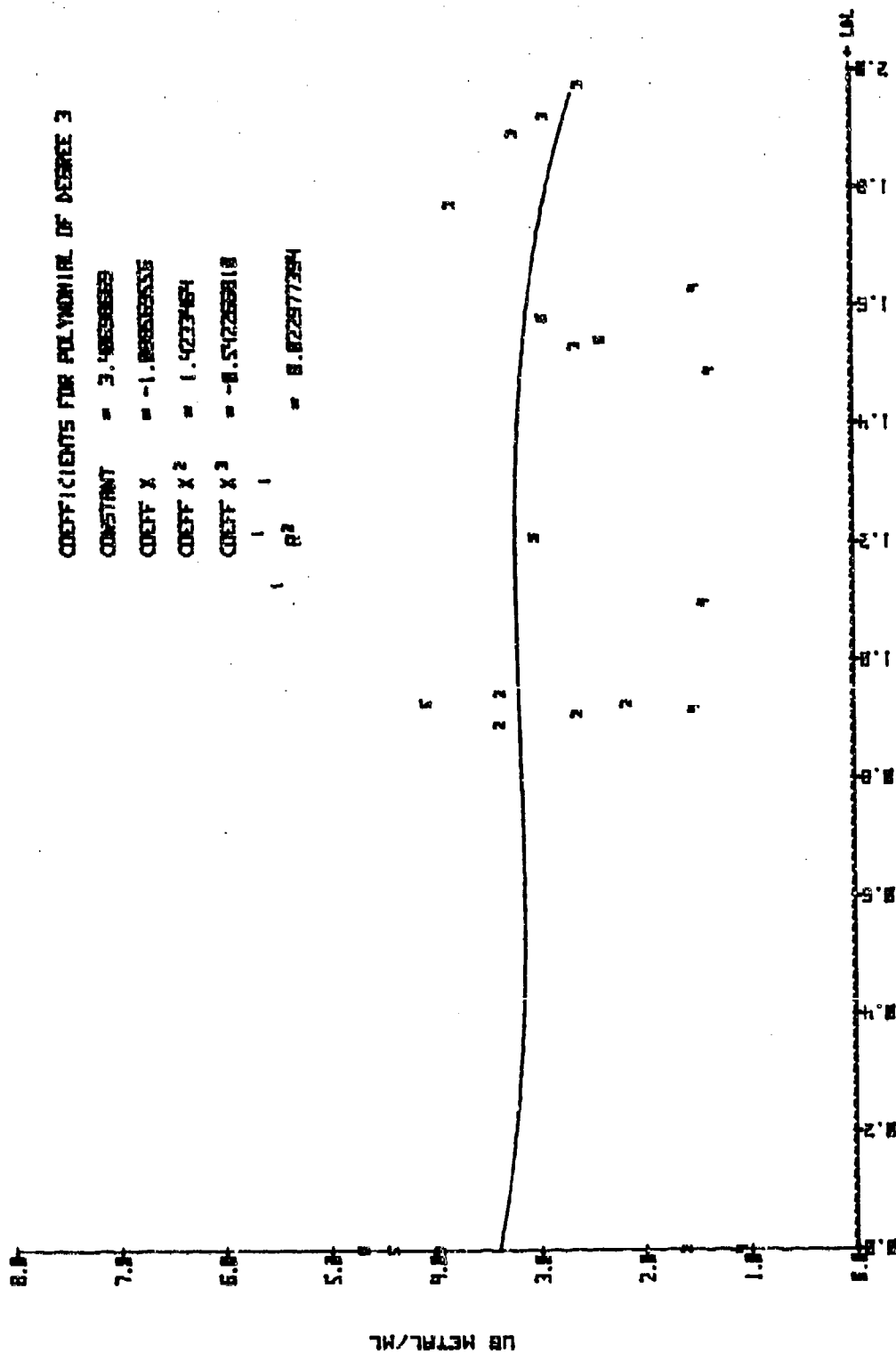


FIGURE 21: ZINC LEACHED FROM ELECTROPLATING WASTE BY LANDFILL LEACHATE

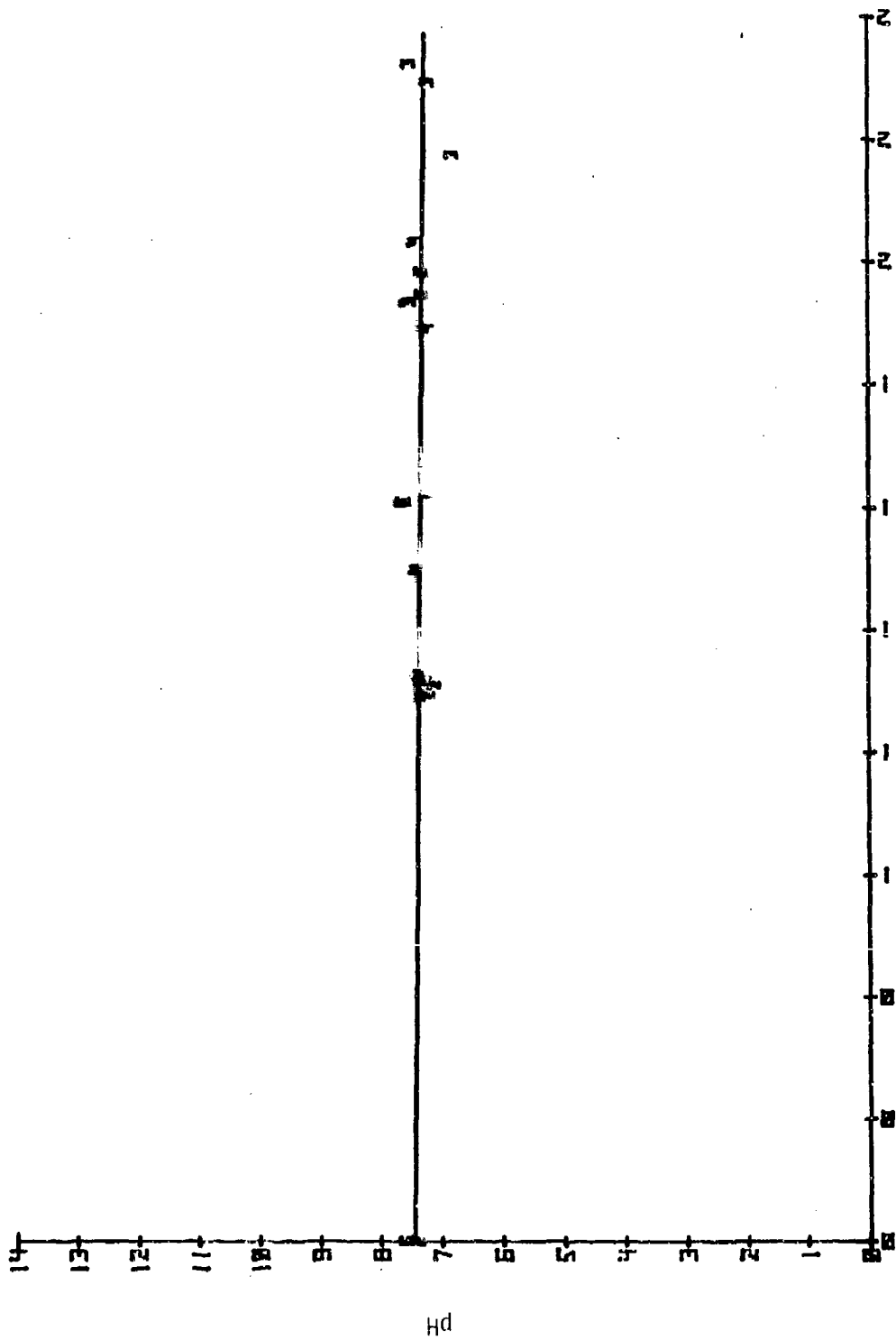


FIGURE 22:: pH OF SOLUTION LEACHED FROM ELECTROPLATING WASTE BY LANDFILL LEACHATE

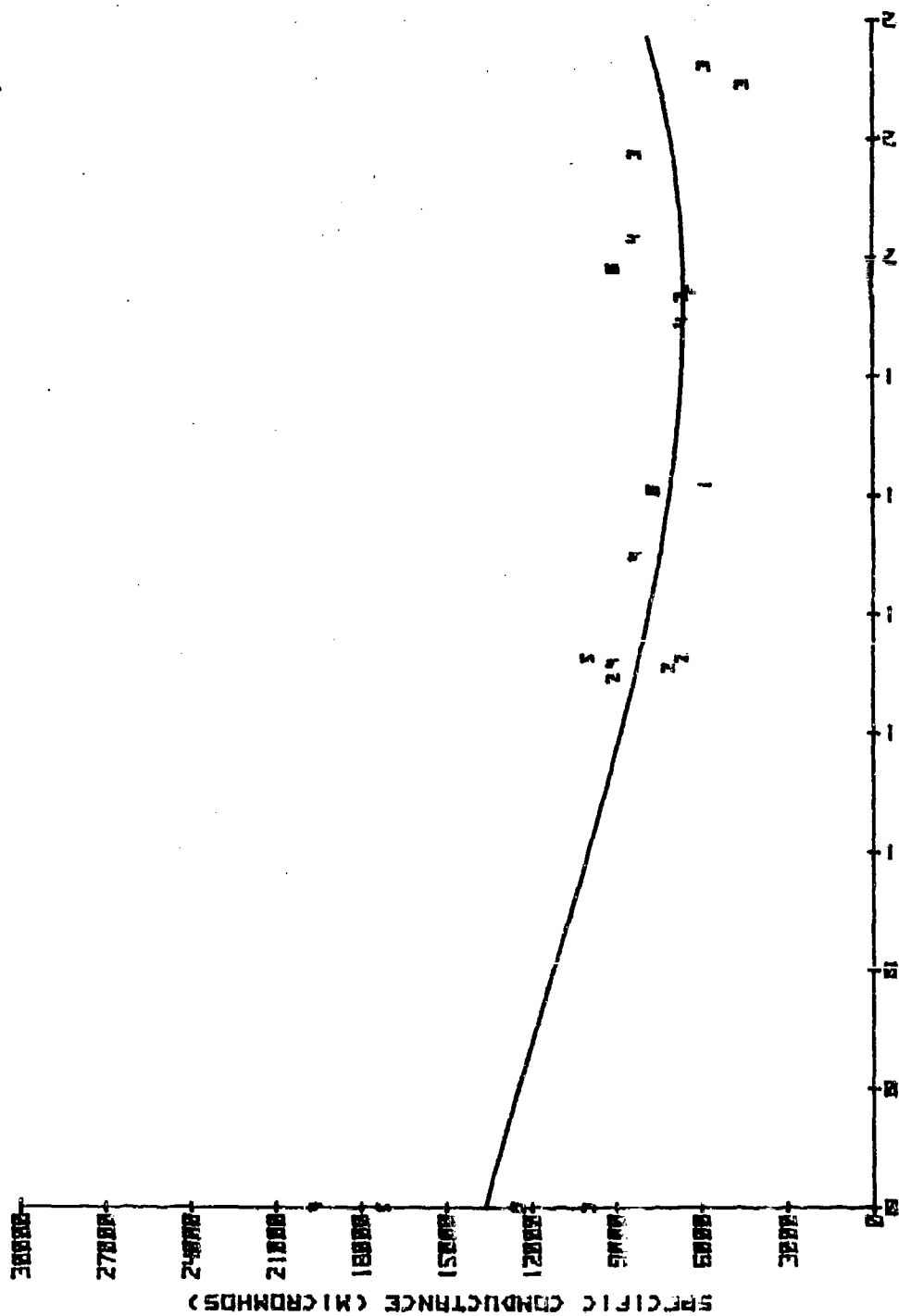


FIGURE 23: CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING
WASTE BY LANDFILL LEACHATE

However, the waste was leached for a much shorter period with municipal landfill leachate than it was with water (1/10 as long). The total weight of copper eluted was 6.3 micrograms/gram waste.

Zinc never exceeded the drinking water standard. A total of 3.9 micrograms zinc/gram waste was eluted. The nickel total was 2.7 micrograms/gram.

As was observed when the waste was leached with distilled water, only a very small fraction of the available metal was eluted from the waste by municipal landfill leachate. The conclusion of this waste with municipal refuse may increase the solubilization of the metals by the municipal landfill leachate.

Nickel-Cadmium Battery Waste

Distilled Water--

The concentrations of cadmium and nickel leached by water from nickel-cadmium battery waste are shown in Figures 24 and 25. The results from all six waste columns are pooled in these plots.

The results plotted in Figures 24 and 25 show that both cadmium and nickel are leached from the waste in extremely high concentration. The initial cadmium concentration was in excess of 3,500 micrograms/milliliter while the nickel was in excess of 60 micrograms/milliliter. Zero-time samples (first liquid from the waste columns) were not collected. As a result, we are uncertain as to the actual initial concentration in the waste leachate samples from the columns. The concentrations of both metals rapidly decreased as the leaching continued. A power regression equation describes the way the metals are leached from the waste. The R-square value indicates that the equation is a very good fit to the experimental data.

This waste is very soluble. Approximately 2 percent (10,900 micrograms cadmium/gram of waste) of the available cadmium was leached from the waste by distilled water (refer to Table 3). Much less nickel was leached from the waste (232 micrograms nickel/gram of waste). The cadmium exceeded the drinking water level many hundred times.

The extremely high concentrations found in the waste column leachate samples obviously cannot be explained by the known solubilities of cadmium and nickel hydroxides (refer to Table 1). These metals were originally precipitated from the wastewater stream as the hydroxides using sodium hydroxide. The batch studies showed that considerable excess basicity remained in the waste sample because of the high pH (pH 9.1). However, upon commencement of leaching with water, some of the first waste leachate samples became acid. The pH values for the waste leachate are shown in Figure 26. An explanation for this occurrence is not readily apparent.

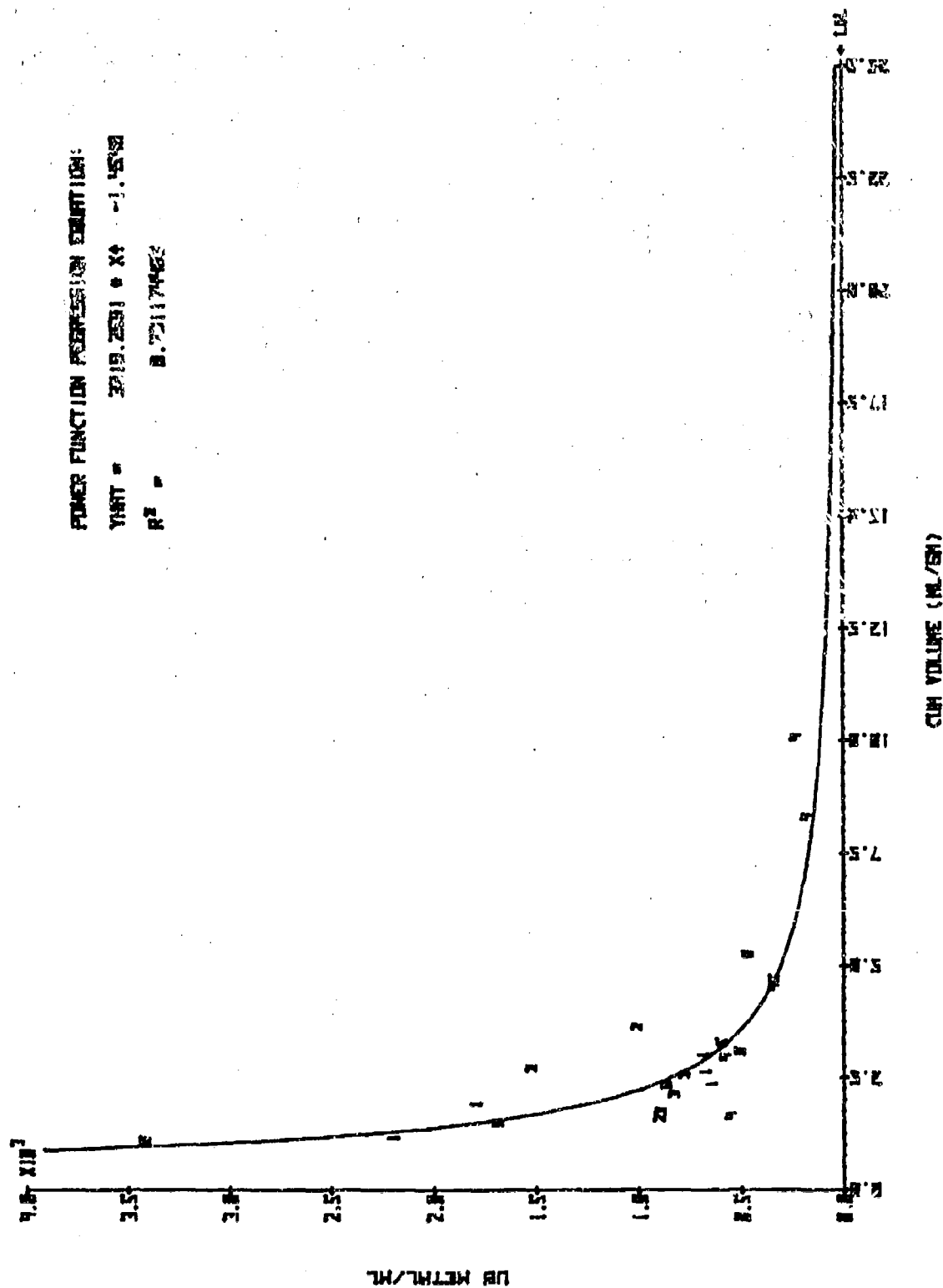
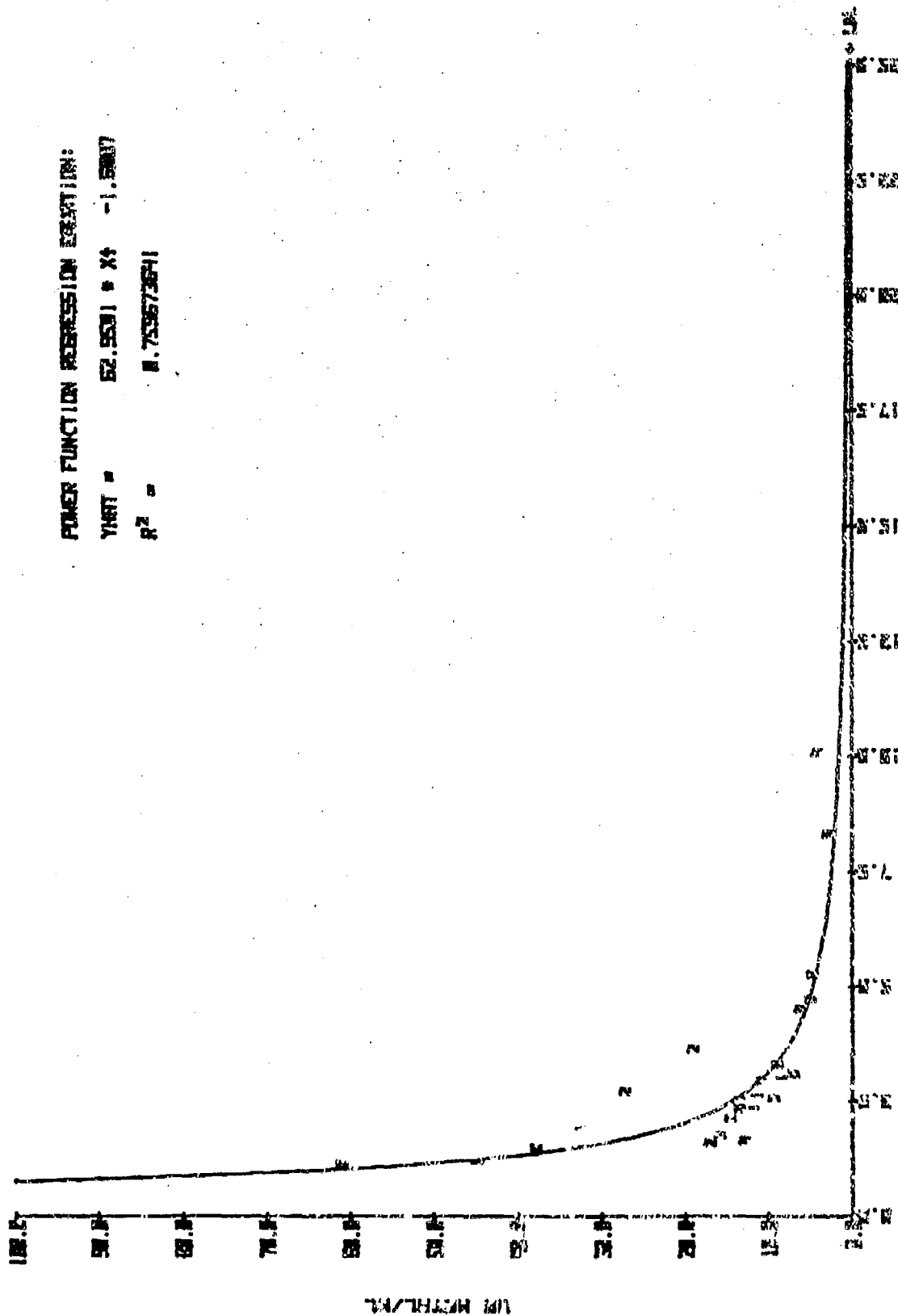


FIGURE 24: CADMIUM LERCHED FROM NI-CO BATTERY WASTE BY WATER

POWER FUNCTION REGRESSION EQUATION:

YHRT = 62.9501 * X^4 - 1.58007

R^2 = 0.753573541



CUM VOLUME (ML/SEC)

FIGURE 25: NICKEL LERCHED FROM NI-CO BATTERY WASTE BY WATER

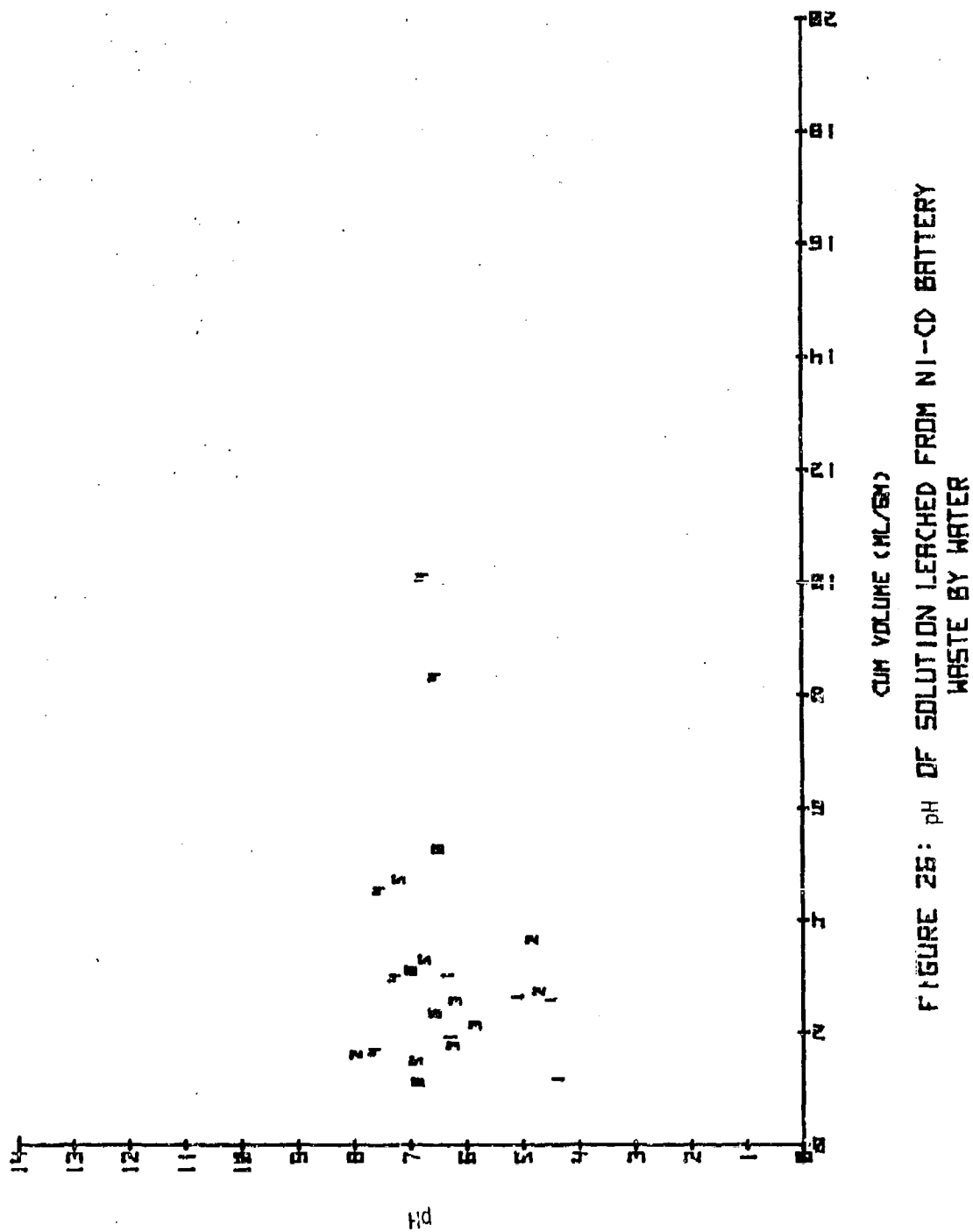


FIGURE 25: pH OF SOLUTION LEACHED FROM NI-CD BATTERY WASTE BY WATER

Specific conductance was measured in all waste column leachate samples. The trend of the specific conductance results closely follows the leaching of cadmium and nickel. The initial samples were very high, indicating a high concentration of soluble ions in the first samples. The conductance values dropped off rapidly as the leaching continued. The results are plotted in Figure 27. The pH and conductance data were too variable to be fitted by regression analysis.

Landfill Leachate--

The results obtained by leaching nickel-cadmium battery waste with municipal landfill leachate are shown in Figures 28 and 29. Cadmium was leached in significantly higher concentrations by municipal landfill leachate than by water. In addition, the concentration remained high and did not drop off as it did when water was used. Nickel was leached at a slightly lower concentration by municipal landfill leachate than by water. However, the concentration remained uniformly high and did not rapidly decrease as it did when water was used.

Municipal landfill leachate dissolved even more cadmium (2 to 3 times) from the waste than did water even though the waste was exposed to only one-third as much leachate as water. The amount of nickel released was comparable to the water leaching results. However, the amount of nickel released from the waste increased as the leaching continued instead of decreasing as it did with water.

Plots of the pH and specific conductance are shown in Figures 30 and 31. The pH remained nearly unchanged during the leaching period showing only a very slight increase. The initial conductance values were very widely scattered. The remaining samples were uniform and were nearly constant at approximately 10,000 micromhos.

It is obvious that disposal of a soluble waste (such as the nickel-cadmium battery waste) which contains hazardous metals could present a hazard. Co-disposal of this type of waste with municipal refuse could aggravate the matter.

Inorganic Pigment Waste

Distilled Water--

Figures 32 through 37 are pooled plots of cadmium, chromium, copper, nickel, lead and zinc concentrations leached from six columns of inorganic pigment waste by water. Cadmium and nickel show similar behavior when leached from the waste. Cadmium started at 0.33 micrograms/milliliter and decreased to near the lower detection limit (l.d.l) after 1,500 to 2,000 milliliters of water had passed through the waste. Nickel started at approximately 0.59 microgram/milliliter and decreased to the lower detection limit after the same total volume of water as in the case of cadmium. Copper started quite low at 0.1 microgram/milliliter but gradually increased

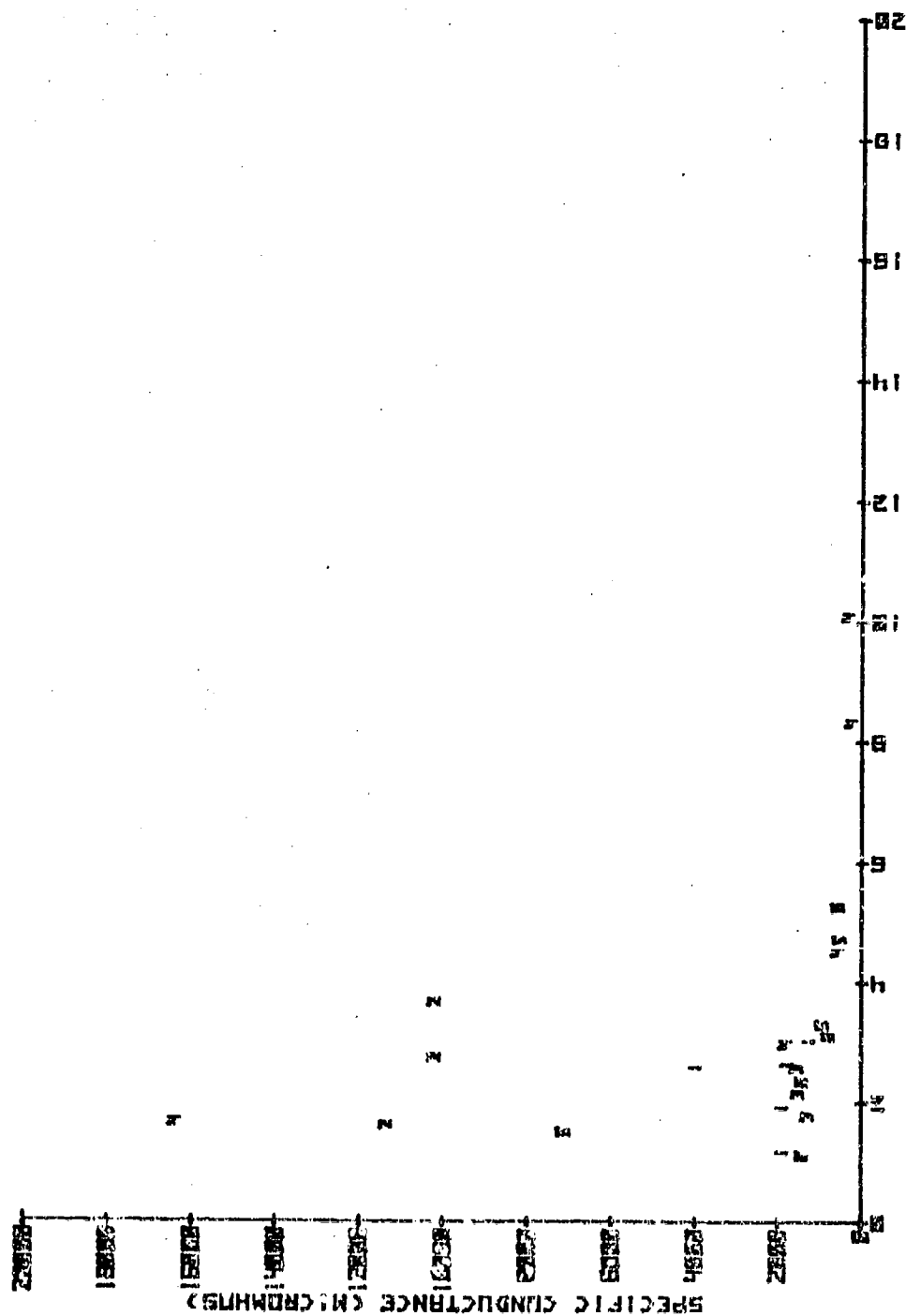
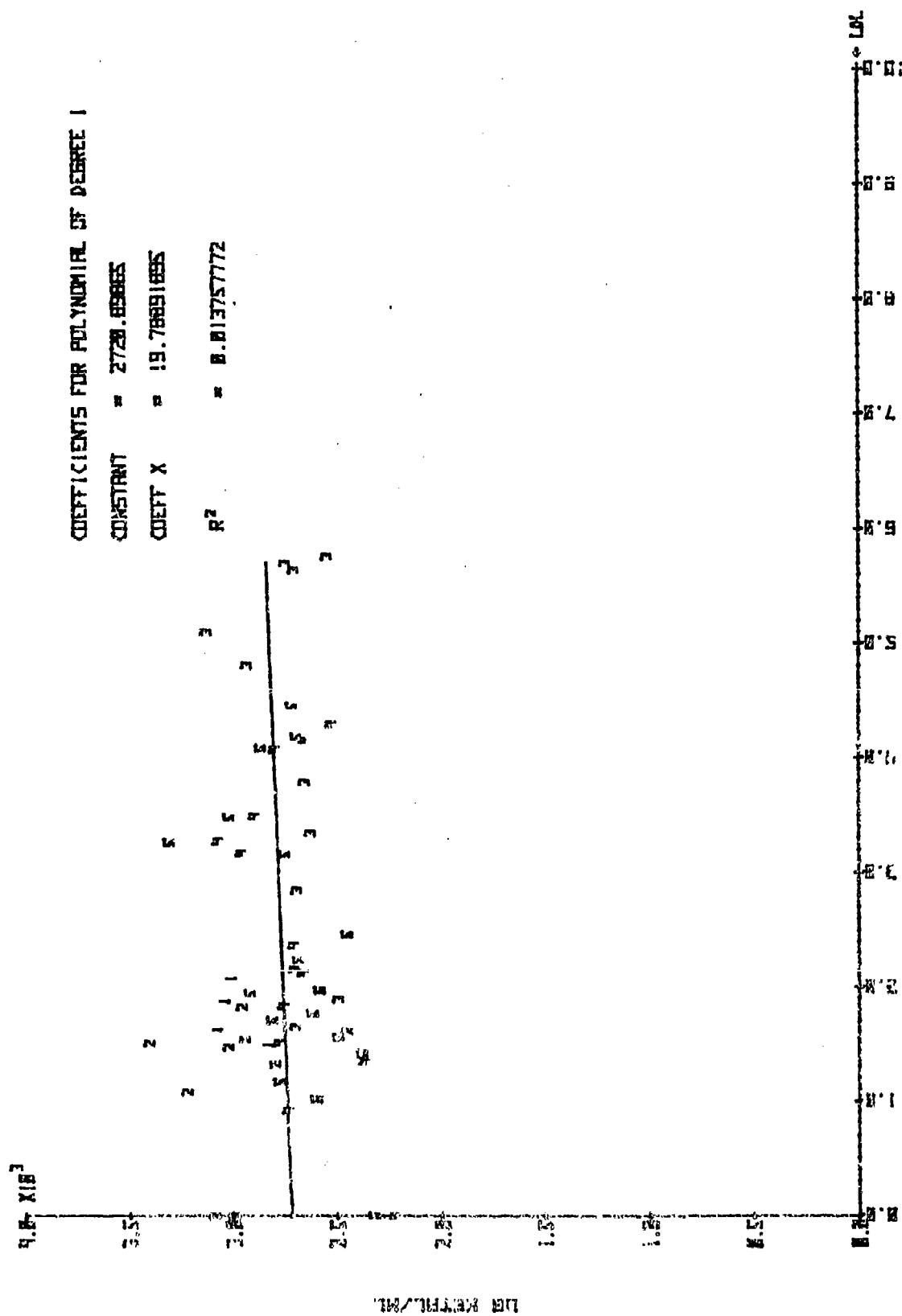
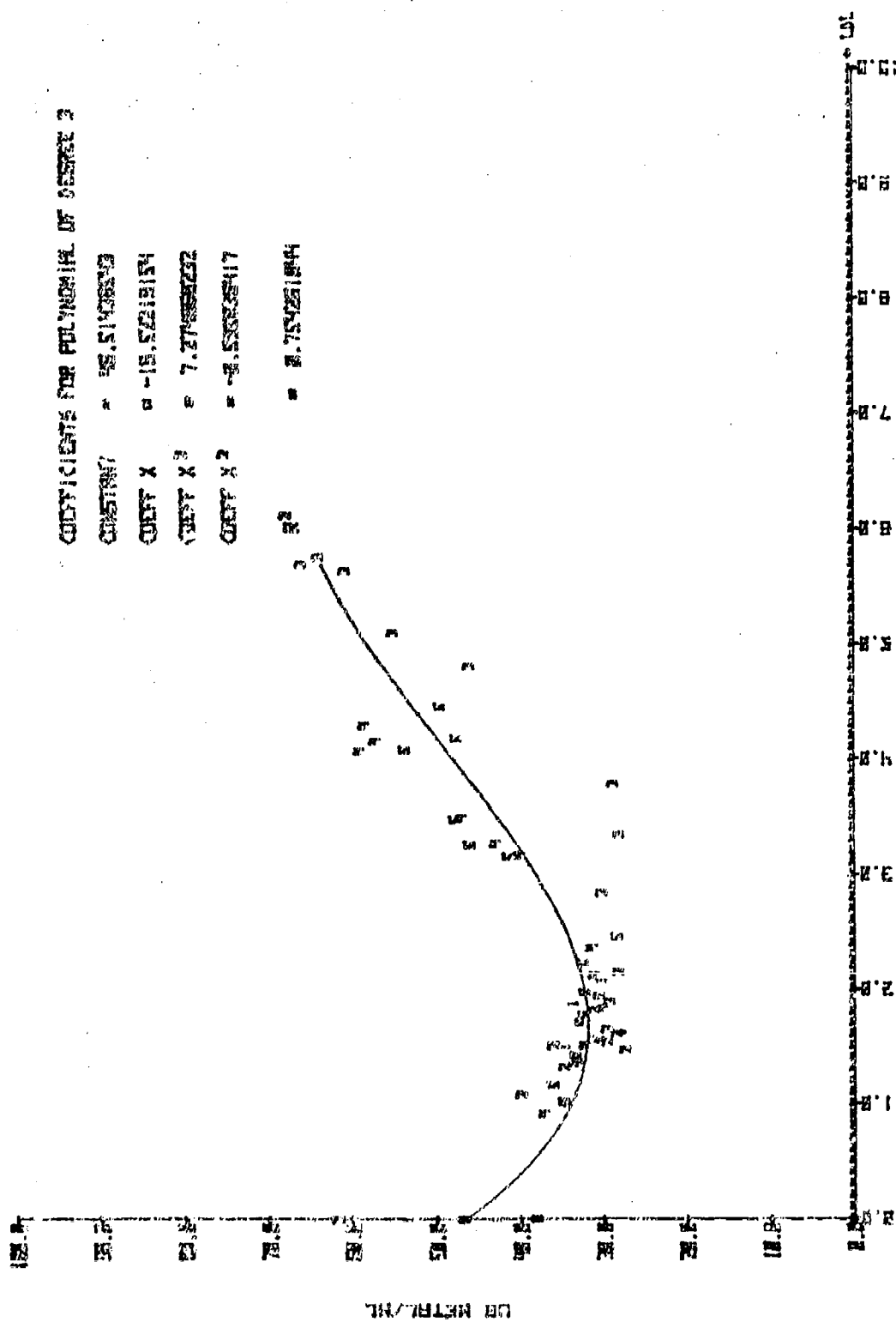


FIGURE 27: CONDUCTANCE OF SOLUTION LEACHED FROM NI-CD BATTERY WASTE BY WATER



CUM VOLUME (ML/CM)

FIGURE 28: CADMIUM LEACHED FROM NI-CD BATTERY WASTE BY LANDFILL LEACHATE



CUM VOLUME (ML/EM)

FIGURE 29: NICKEL LEACHED FROM NI-CD BATTERY WASTE BY LANDFILL LEACHATE

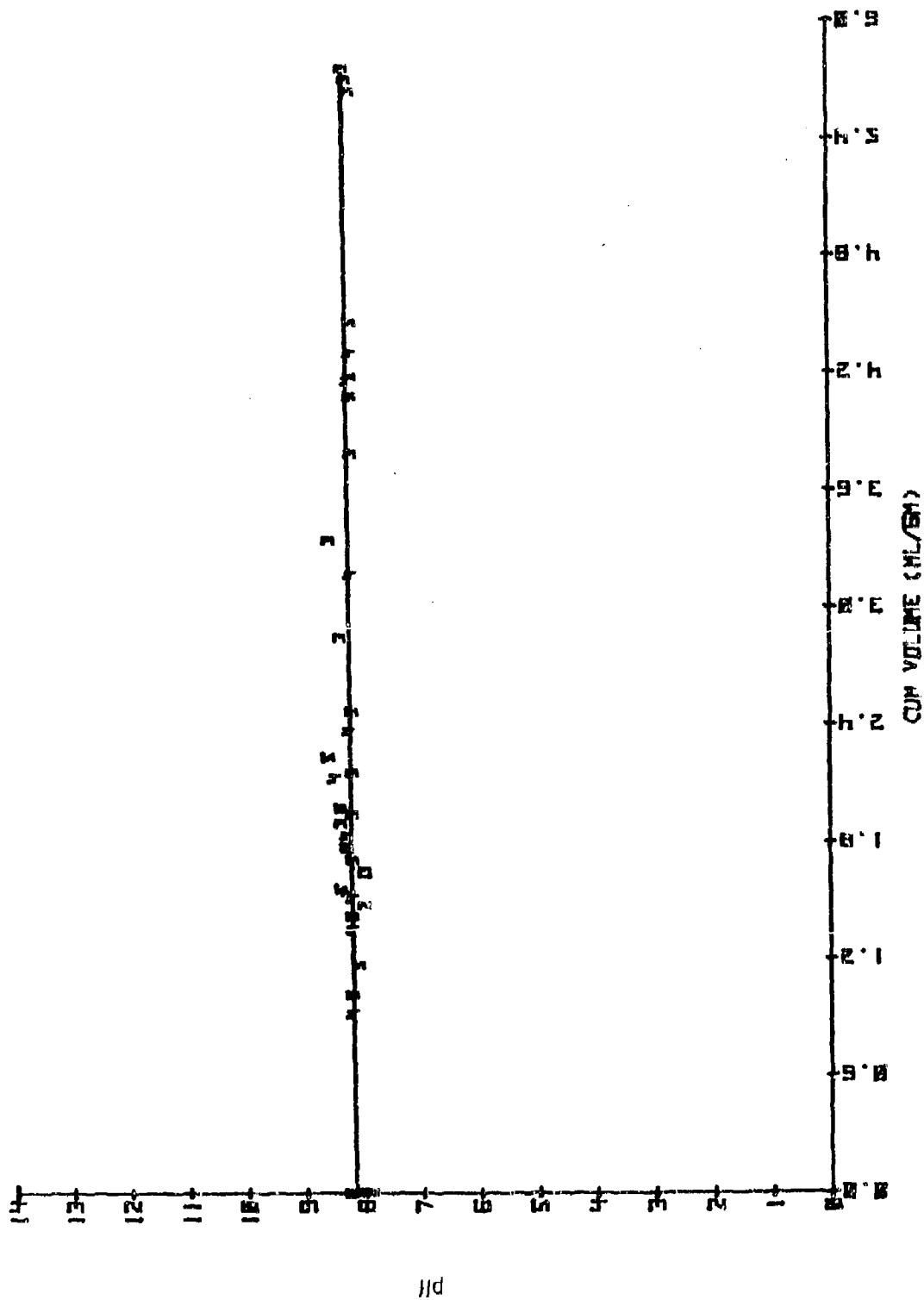


FIGURE 30: pH OF SOLUTION LEACHED FROM NI-CD BATTERY WASTE BY LANDFILL LEACHATE

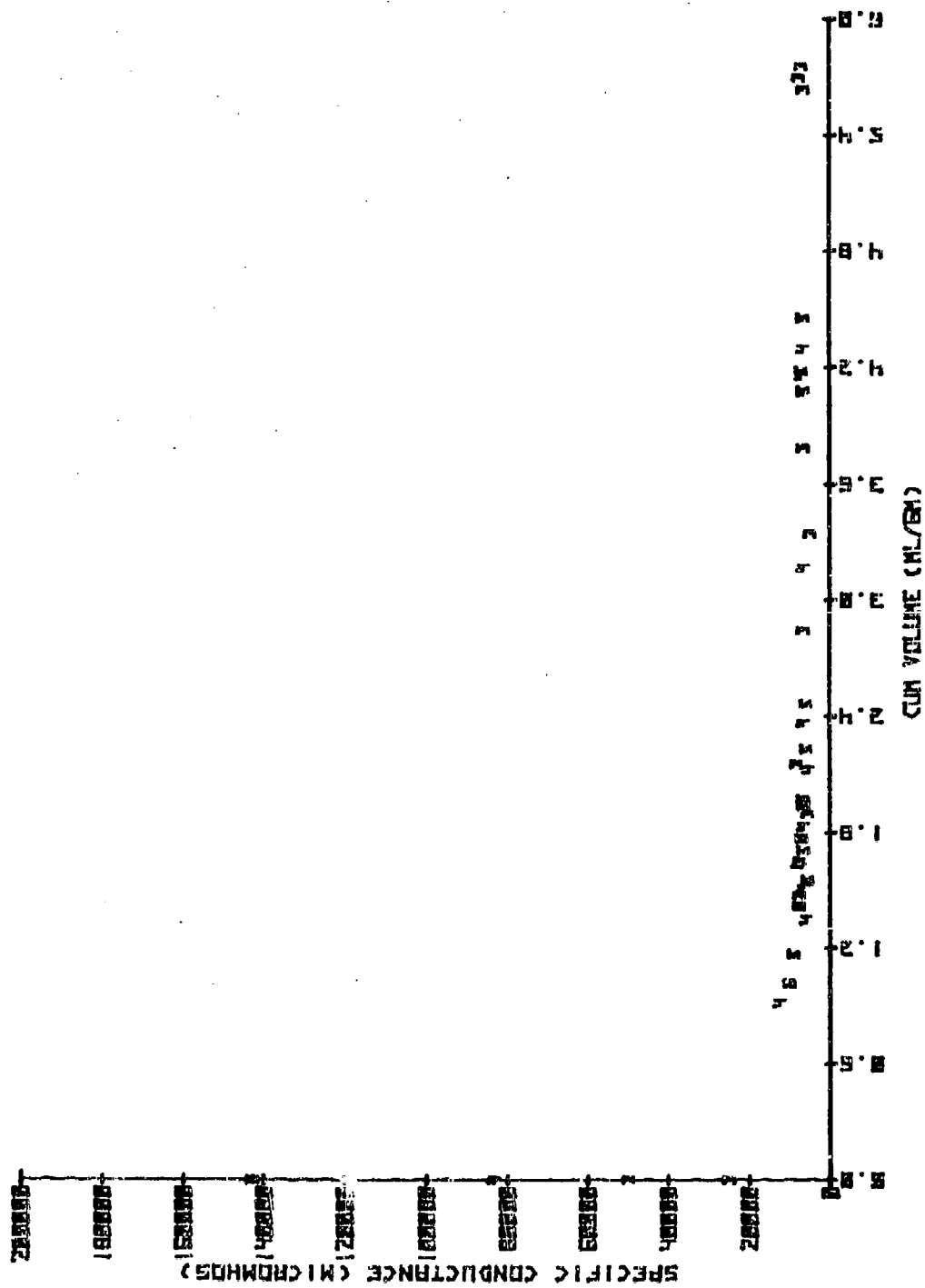


FIGURE 31: CONDUCTANCE OF SOLUTION LEACHED FROM NI-CD BATTERY
WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 0.333816031
 COEFF X = -0.11853471
 COEFF X² = 0.017756739
 COEFF X³ = -1.25799E-03
 COEFF X⁴ = 4.56619E-05
 COEFF X⁵ = -8.09655E-07
 COEFF X⁶ = 5.53989E-09

R² = 0.724834542

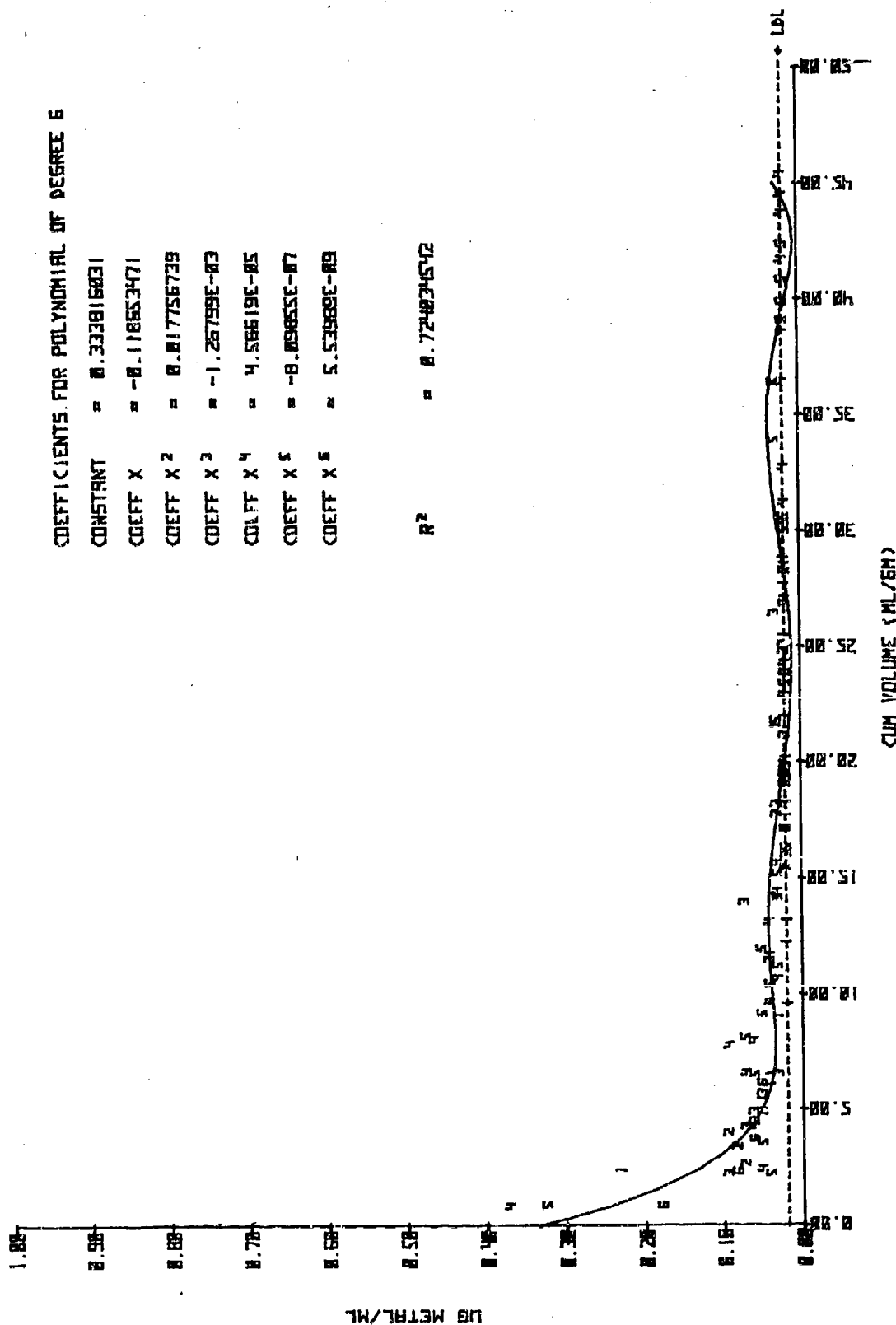


FIGURE 32: CADMIUM LEACHED FROM PIGMENT WASTE BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 1.883532114
 COEFF X = -8.125328554
 COEFF X² = 8.884311176
 COEFF X³ = -4.474808-03
 COEFF X⁴ = 1.8833382-04
 COEFF X⁵ = -3.8837782-07

R² = 0.98377853

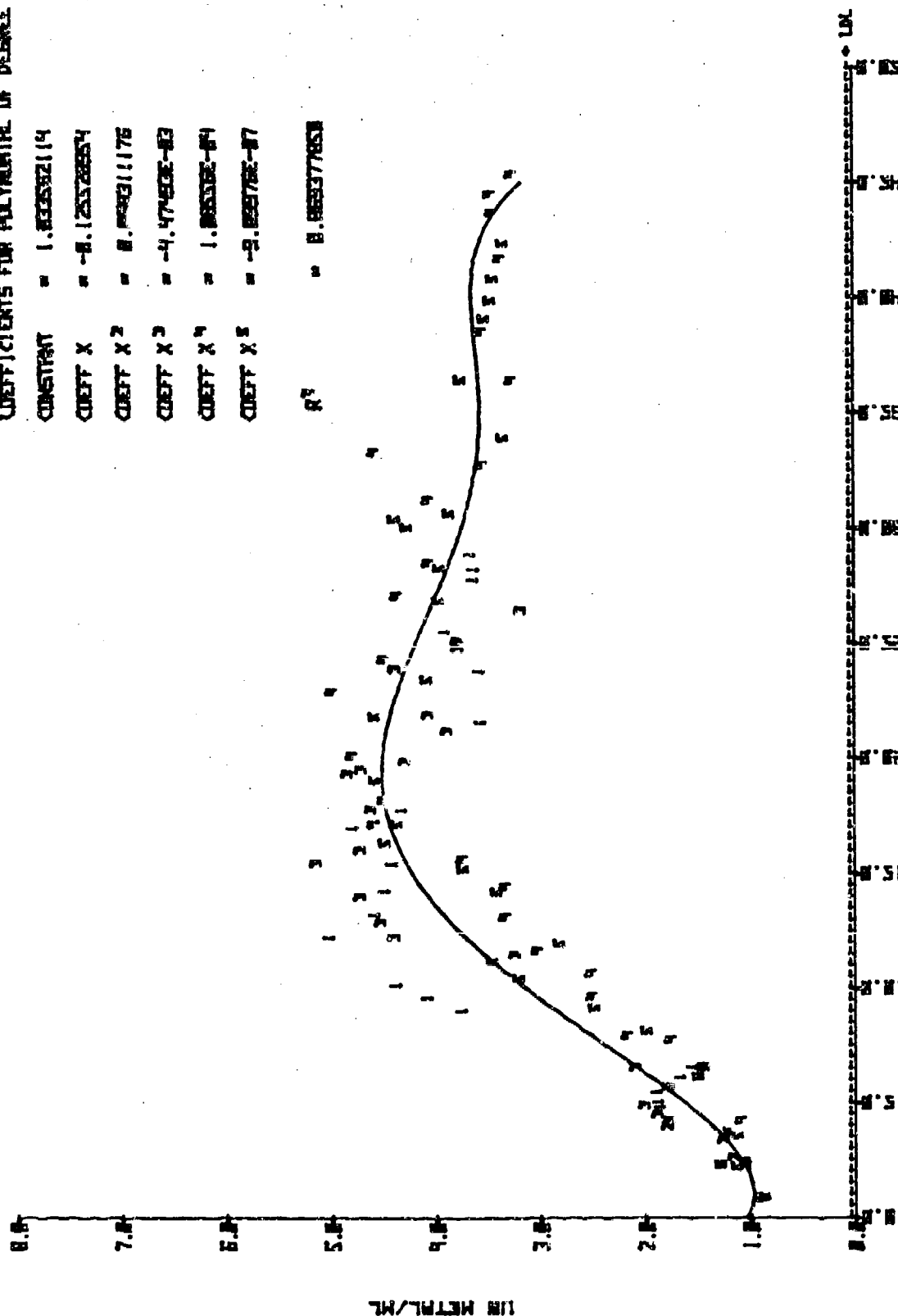


FIGURE 33: CHROMIUM LERCHED FROM PIGMENT WASTE BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.185273652

COEFF X = -0.023372828

COEFF X² = 2.24388E-03

COEFF X³ = -7.16738E-05

COEFF X⁴ = 7.44811E-07

COEFF X⁵ = 9.48888E-10

R² = 0.508798559

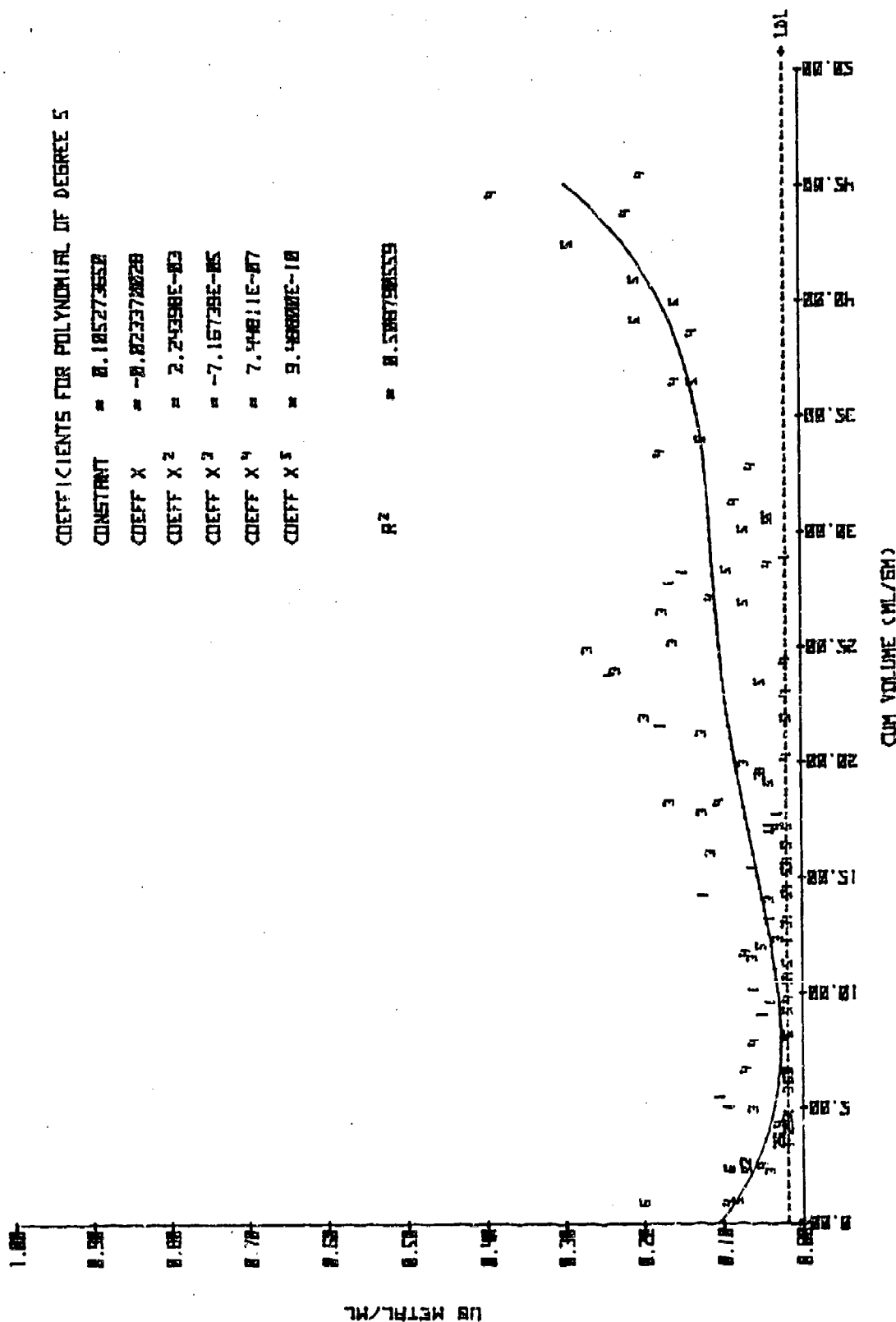


FIGURE 34: COPPER LEACHED FROM PIGMENT WASTE BY WATER

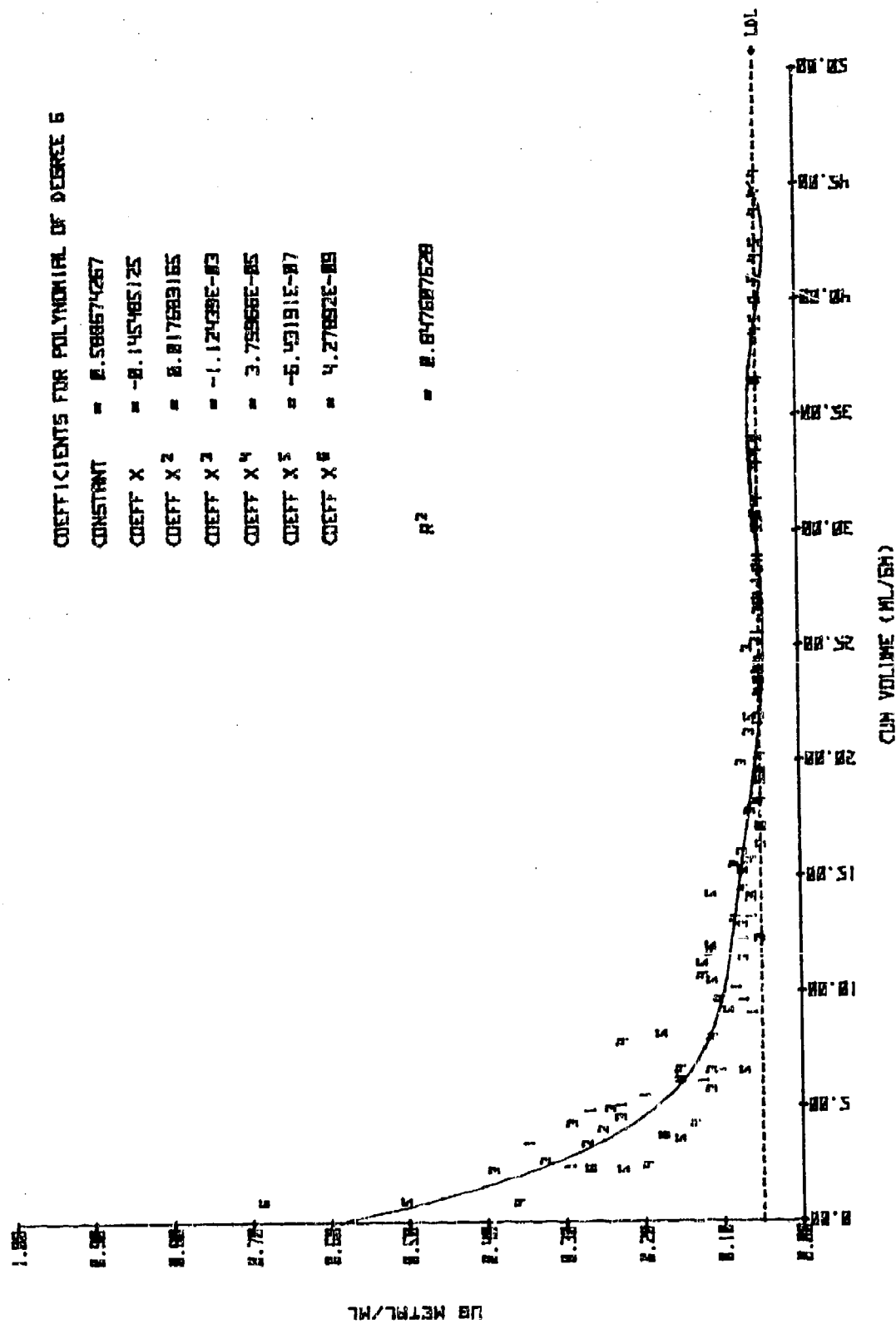


FIGURE 35: NICKEL LEACHED FROM PIGMENT WASTE BY WATER

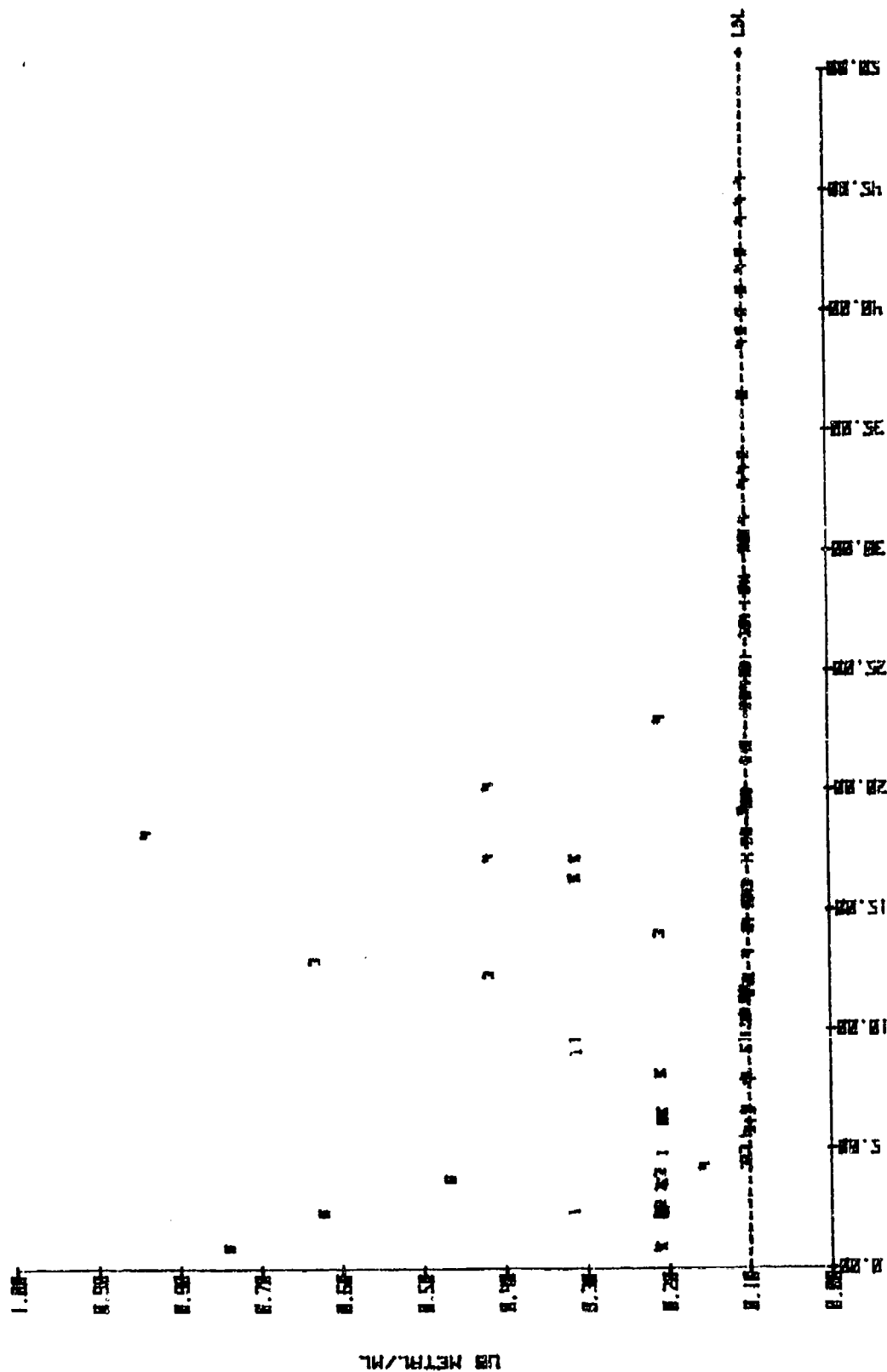


FIGURE 36: LEAD LERCHED FROM PIGMENT WASTE BY WATER

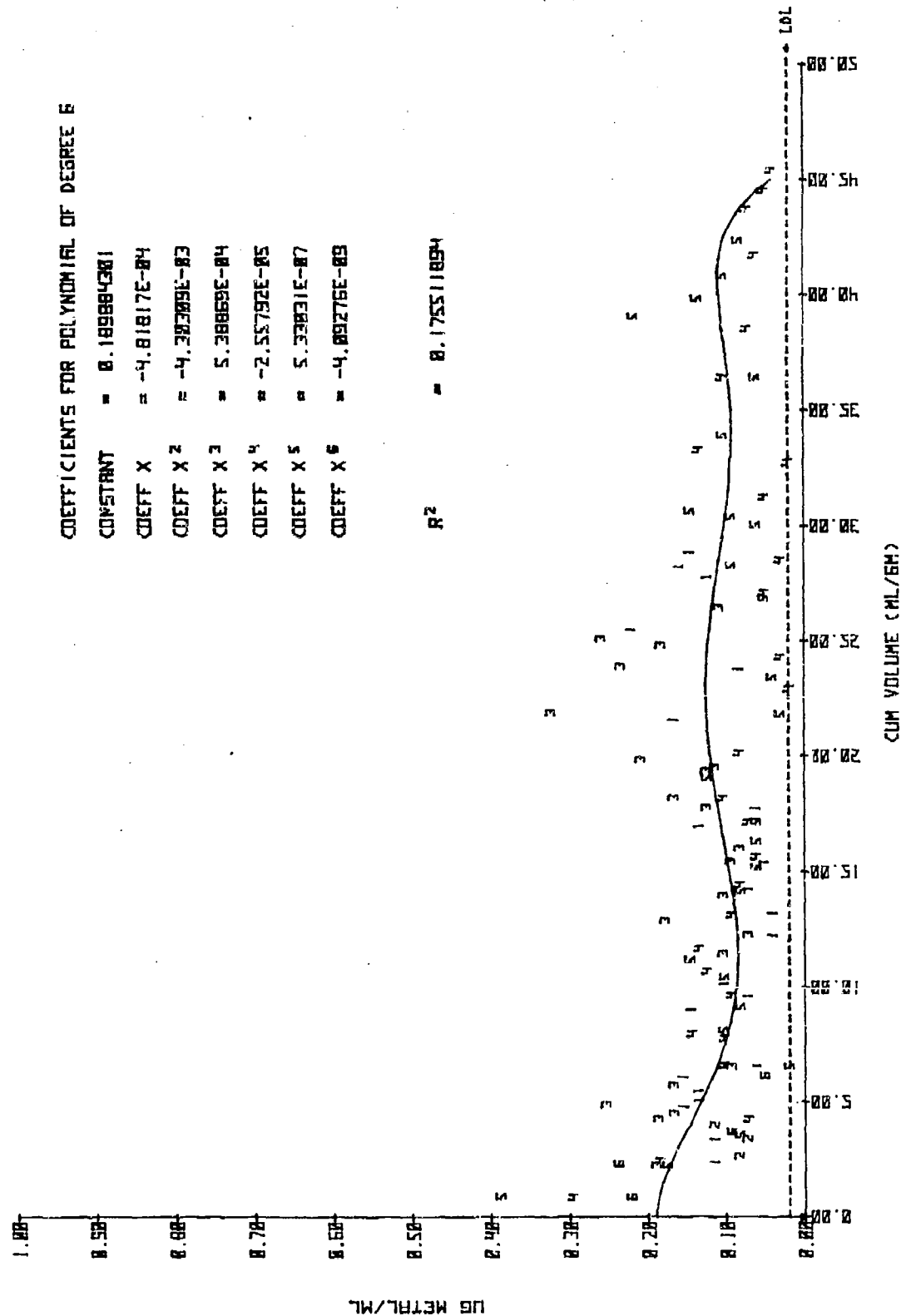


FIGURE 37: ZINC LEACHED FROM PIGMENT WASTE BY WATER

as the leaching continued to a final concentration of approximately 0.3 microgram/milliliter. The initial concentration of chromium was 1.0 microgram/milliliter. Its concentration increased sharply to a high concentration of 4.5 micrograms/milliliter after being leached with 1,500 to 2,000 milliliters of water then gradually decreased to a final concentration of approximately 3.0 micrograms/milliliter. Lead was found only sporadically in the waste leachate samples, reaching as high as 0.8 microgram/milliliter in one sample. However, the vast majority of samples were below the detection limit of the AAS method (0.1 $\mu\text{g/ml}$). As a result, the values were plotted but no attempt was made to derive an equation describing the leaching of lead. The zinc results were quite scattered but the concentration in most samples was above the detection limit. The R-square for the polynomial equation is quite poor but the equation provides a rough description of the leaching of zinc from the waste.

Chromium was solubilized to the greatest extent when this sample of inorganic pigment waste was leached with water. A total of 47.7 micrograms chromium/gram of waste was leached from the waste. This is only a small fraction of the potentially available chromium in the waste (see Table 4). At times its concentration exceeded the drinking water standard in the waste leachate nearly one hundred times. It is apparent that the chromium leached from the waste was in some other form than chromium hydroxide. Chromium is amphoteric and its minimum solubility is near pH 7. The pH of the samples measured during the leaching experiments started at approximately eight and decreased to near neutrality as shown in Figure 38. The concentration of chromium in the waste leachate samples increased during this time which is the reverse of what should have happened if the chromium in the waste samples was present as the hydroxide salt. It is felt that more soluble complex chromate ions were formed during the leaching similar to that described before for zinc. As the more soluble and/or common ions washed from the waste, and the specific conductance (Figure 39) decreased, more of the complex chromate ions came into solution.

Nickel and zinc were next in total amount leached from the waste (3.0 and 2.2 micrograms/gram). However, a drinking water standard is not available for nickel. Concentrations of zinc did not exceed the water standard.

Cadmium and copper leached from the waste in substantial amounts. A total of 1.2 micrograms cadmium/gram of waste was leached from the waste by water, while 1.0 microgram of copper/gram of waste was leached. Both exceeded the drinking water standard, with the highest concentrations of cadmium appearing in the first waste leachate samples and of copper in the later samples.

Although lead concentrations in waste leachate samples often exceeded drinking water standards, it is difficult to determine an accurate value for the amount of lead leached from the waste because of its sporadic appearance in the leachate.

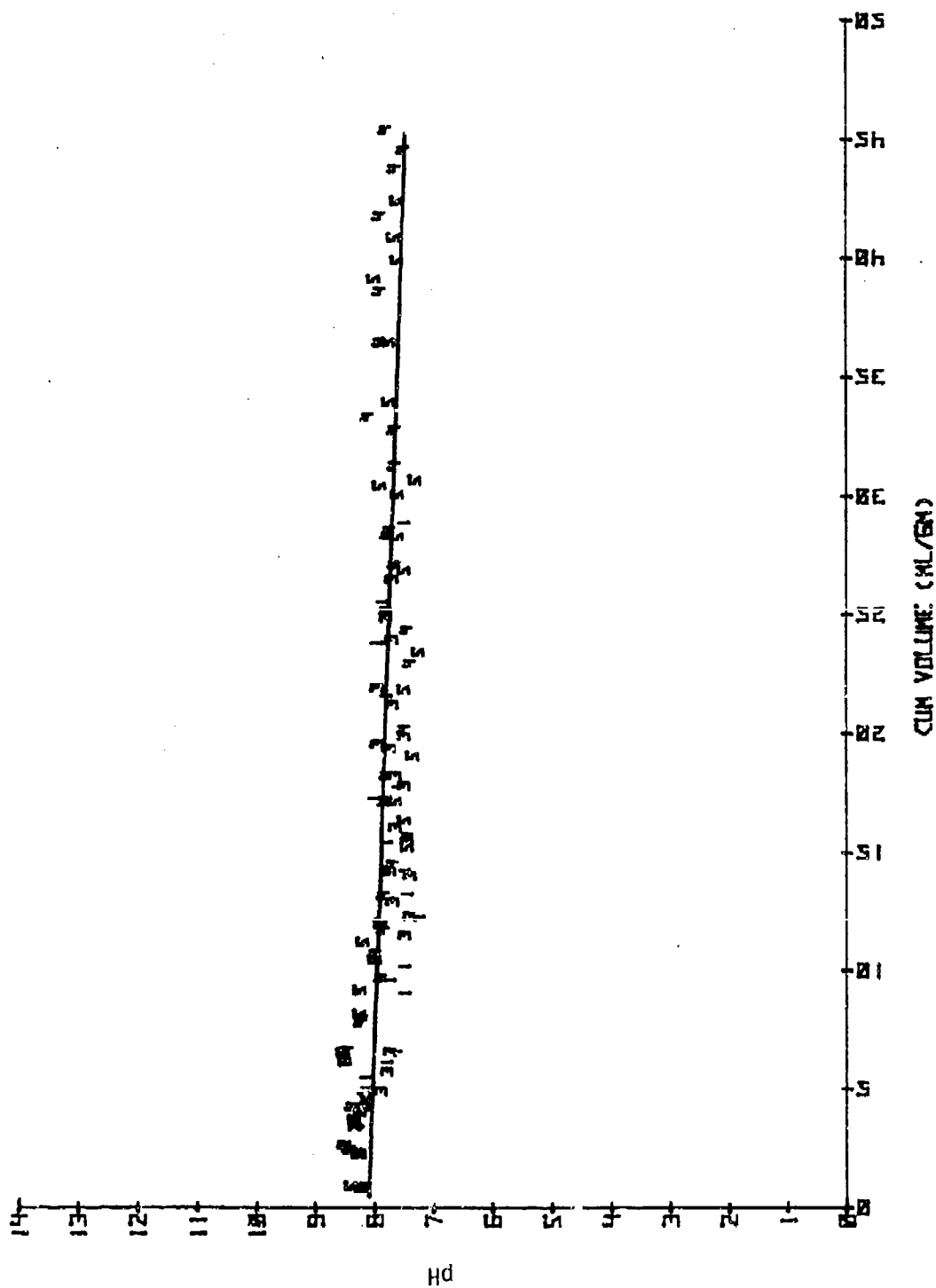


FIGURE 3B: pH OF SOLUTION LEACHED FROM PIGMENT WASTE BY WATER

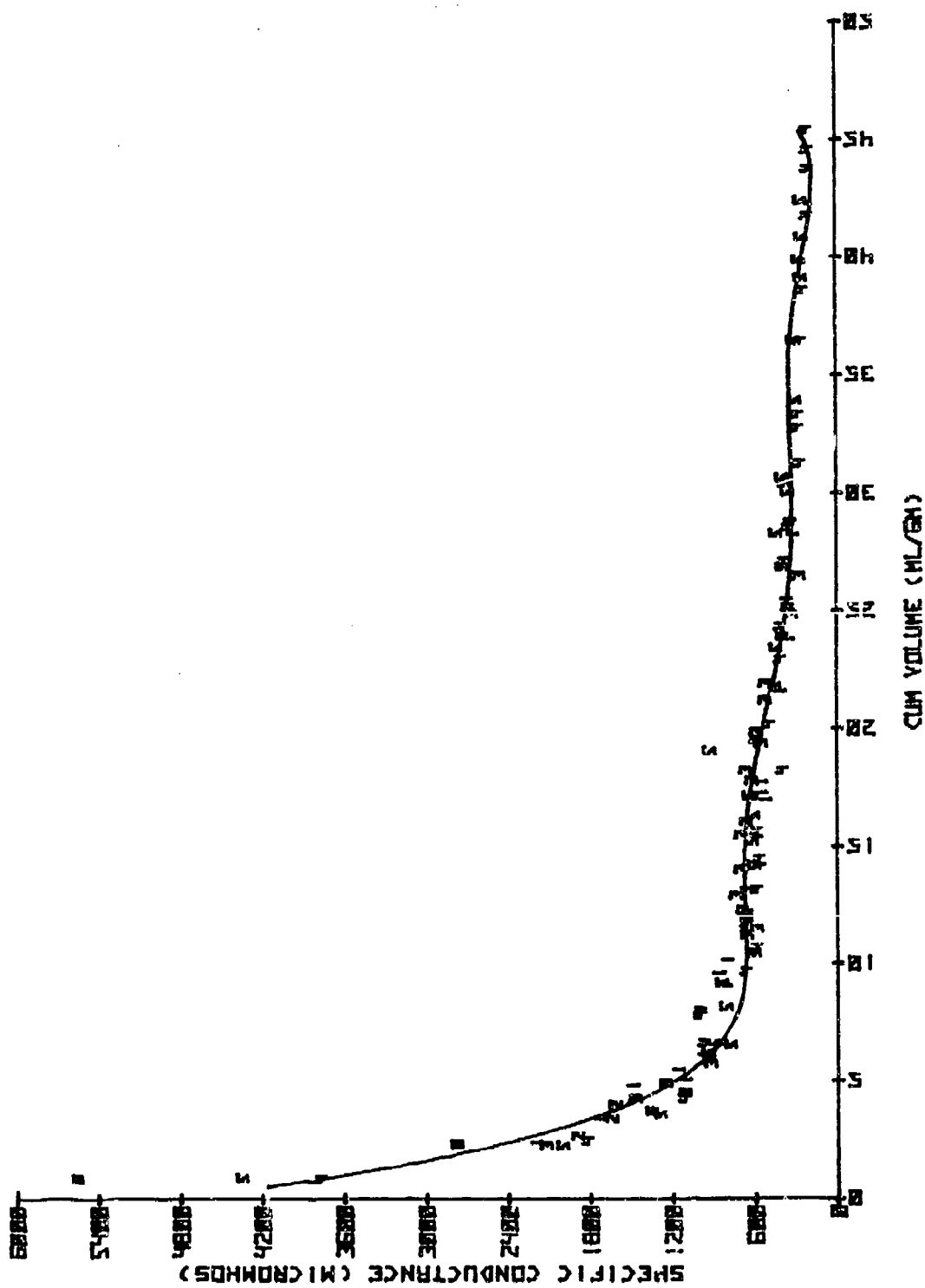


FIGURE 39: CONDUCTANCE OF SOLUTION LERCHED FROM PIGMENT WASTE BY WATER

Landfill Leachate--

Figures 40 through 45 are pooled plots of cadmium, chromium, copper, lead, nickel and zinc concentrations leached from pigment waste by municipal landfill leachate. The plots show that except for chromium and nickel, municipal landfill leachate leached much more of each metal from this waste than did water. Cadmium was four times greater (3.3 micrograms/gram of waste); copper was nine times greater (3.1 micrograms/gram of waste); lead was consistently found in the leachate whereas with water it was not (3.7 micrograms/gram); and zinc was seven times greater (6.1 micrograms/gram of waste). Chromium leached from the waste by municipal landfill leachate exceeded the amount removed by an equivalent volume of water by 1.2 times, for a total of 6.9 micrograms/gram of waste, but never reached as high a concentration in the municipal landfill leachate samples as when water was used.

Chromium, lead, cadmium and copper were found in the waste leachate at concentrations exceeding the drinking water standard. Although zinc was found in the samples in relatively high concentrations, it did not exceed the drinking water standard.

Figures 46 and 47 are pH and specific conductance plots for the municipal landfill leachate pigment waste sample. The pH was uniform throughout the leaching of the waste and only slightly less basic than that obtained from the water leaching experiments. The conductance is much greater when the pigment waste was leached with municipal landfill leachate as compared to water leaching.

Water Base Paint Waste

Distilled Water--

Figures 48 through 50 are pooled plots of chromium, copper, and zinc concentrations leached from water base paint waste by water. Cadmium, nickel, and lead appeared sporadically in the samples. The R-square values for the derived equations were poor for these metals and therefore were not plotted, because the resultant plot would not accurately quantitate the weight of metal leached from the waste.

Zinc was leached from the waste in the greatest amount (3.1 micrograms/gram of waste). However, it did exceed the drinking water standard. Chromium and copper were often found in concentrations greater than the drinking water standards. The total for each were 2.3 and 1.0 microgram/gram of waste, respectively. The other metals sporadically exceeded the drinking water standards.

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 4

CONSTANT = 1.312263898

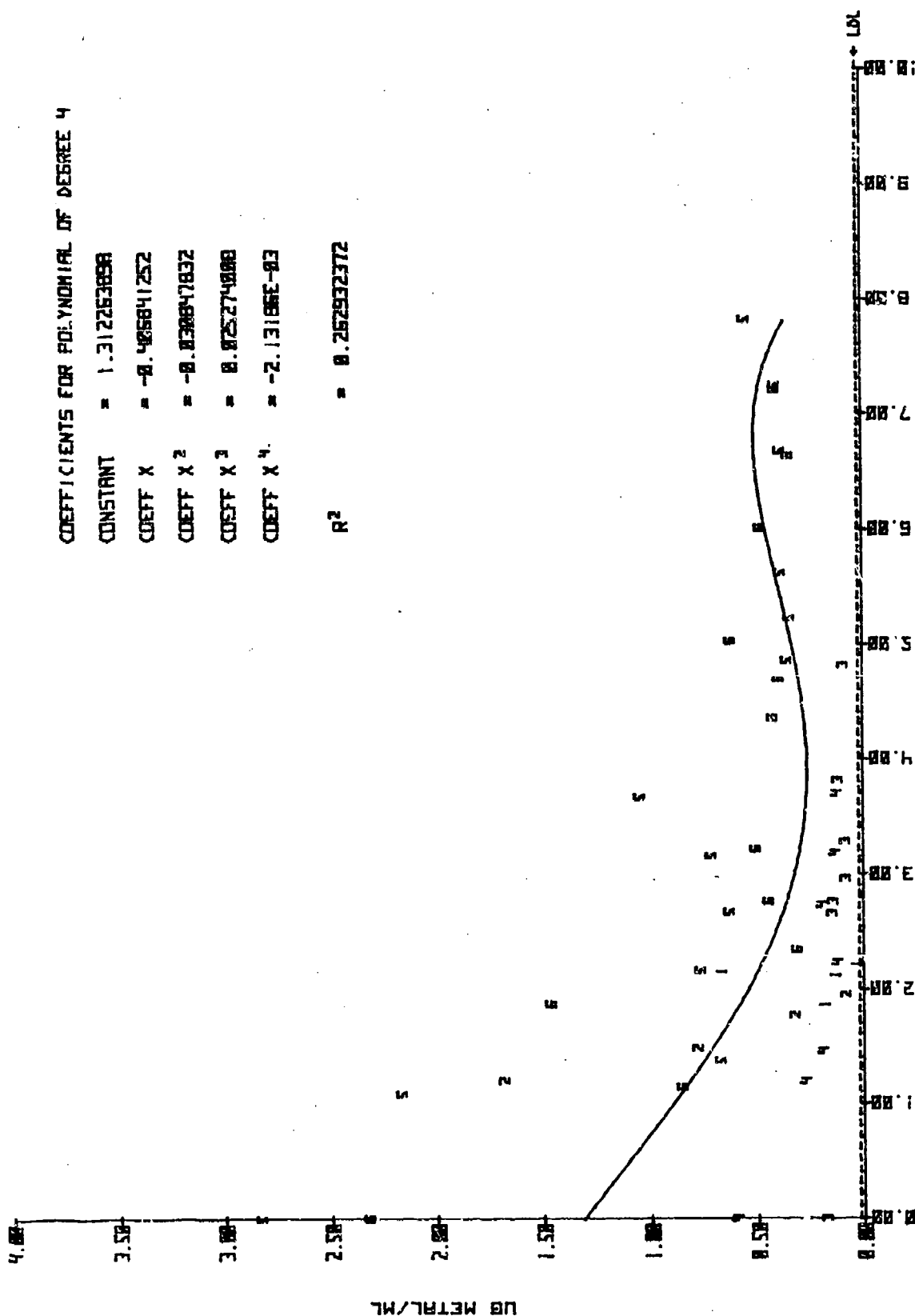
COEFF X = -0.405841252

COEFF X² = -0.030847832

COEFF X³ = 0.025274000

COEFF X⁴ = -2.13186E-03

R² = 0.262932372



CUM VOLUME (NL/GM)

FIGURE 40: CADMIUM LEACHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

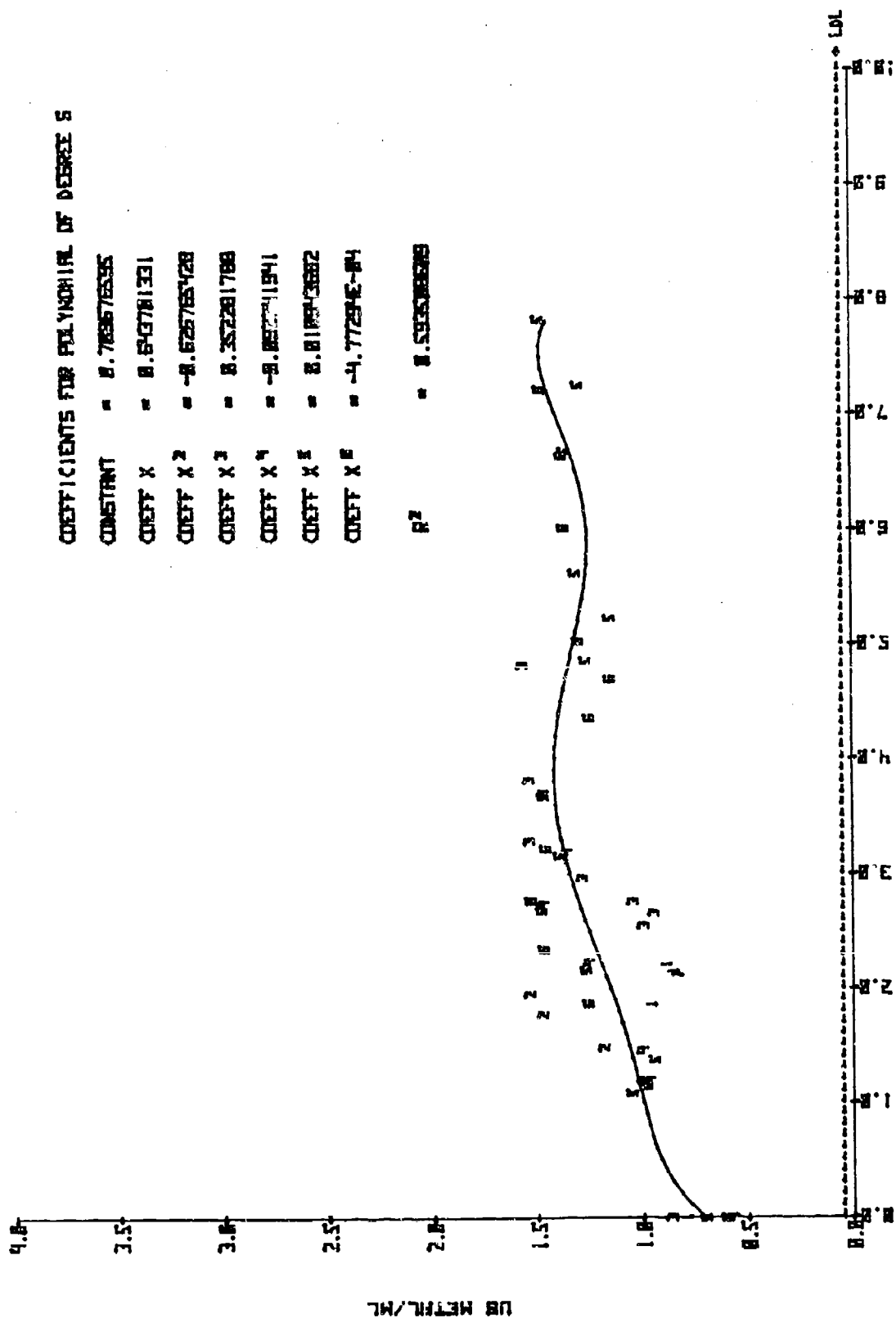


FIGURE 41: CHROMIUM LEACHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 8.2511476E-01

COEFF X = 8.1716402E-04

COEFF X² = -8.1588885E-08

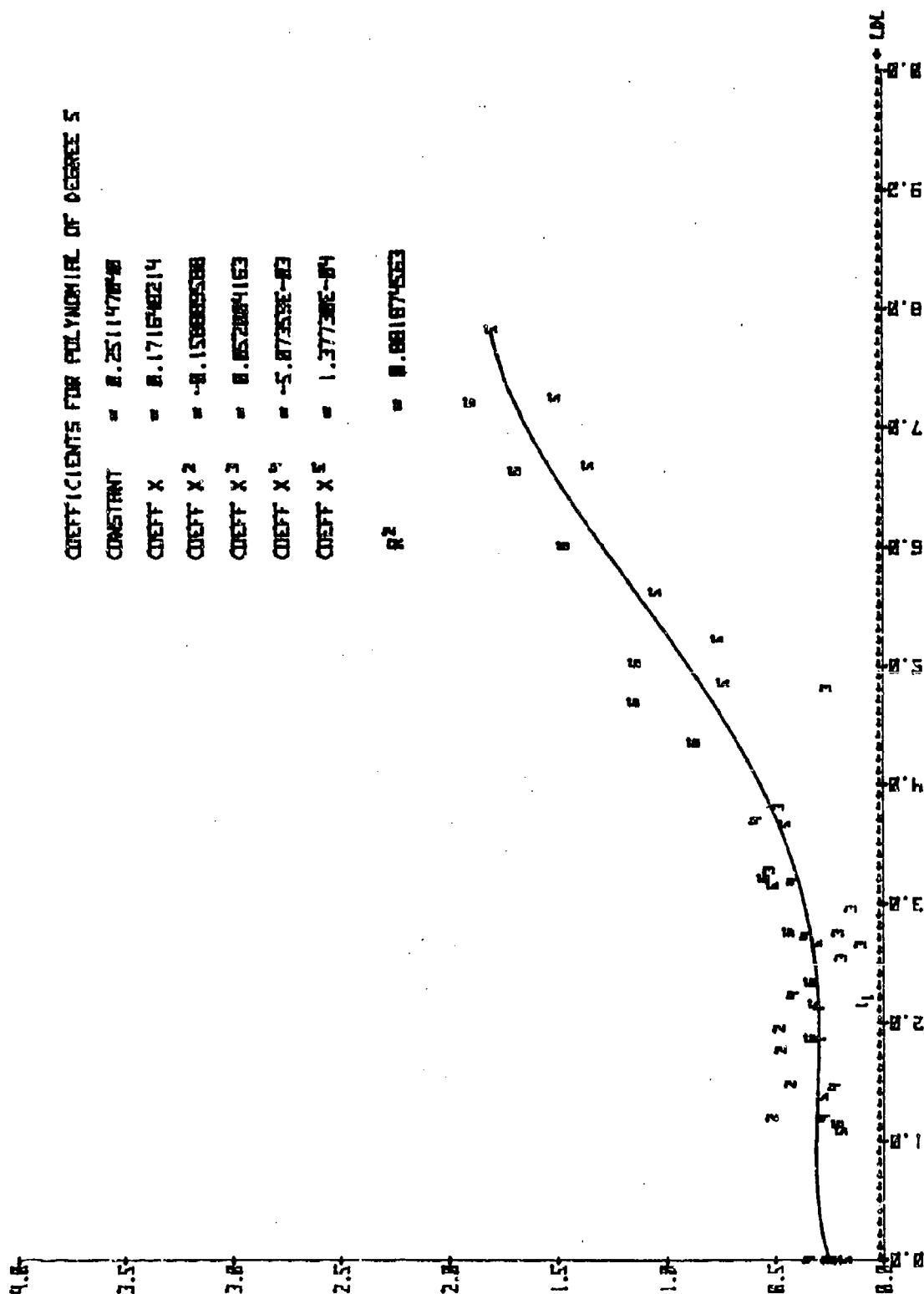
COEFF X³ = 8.8528841E-03

COEFF X⁴ = -5.877353E-03

COEFF X⁵ = 1.37738E-04

R² = 0.981874563

UG METAL/ML



CUM VOLUME (ML/GH)

FIGURE 42: COPPER LEACHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

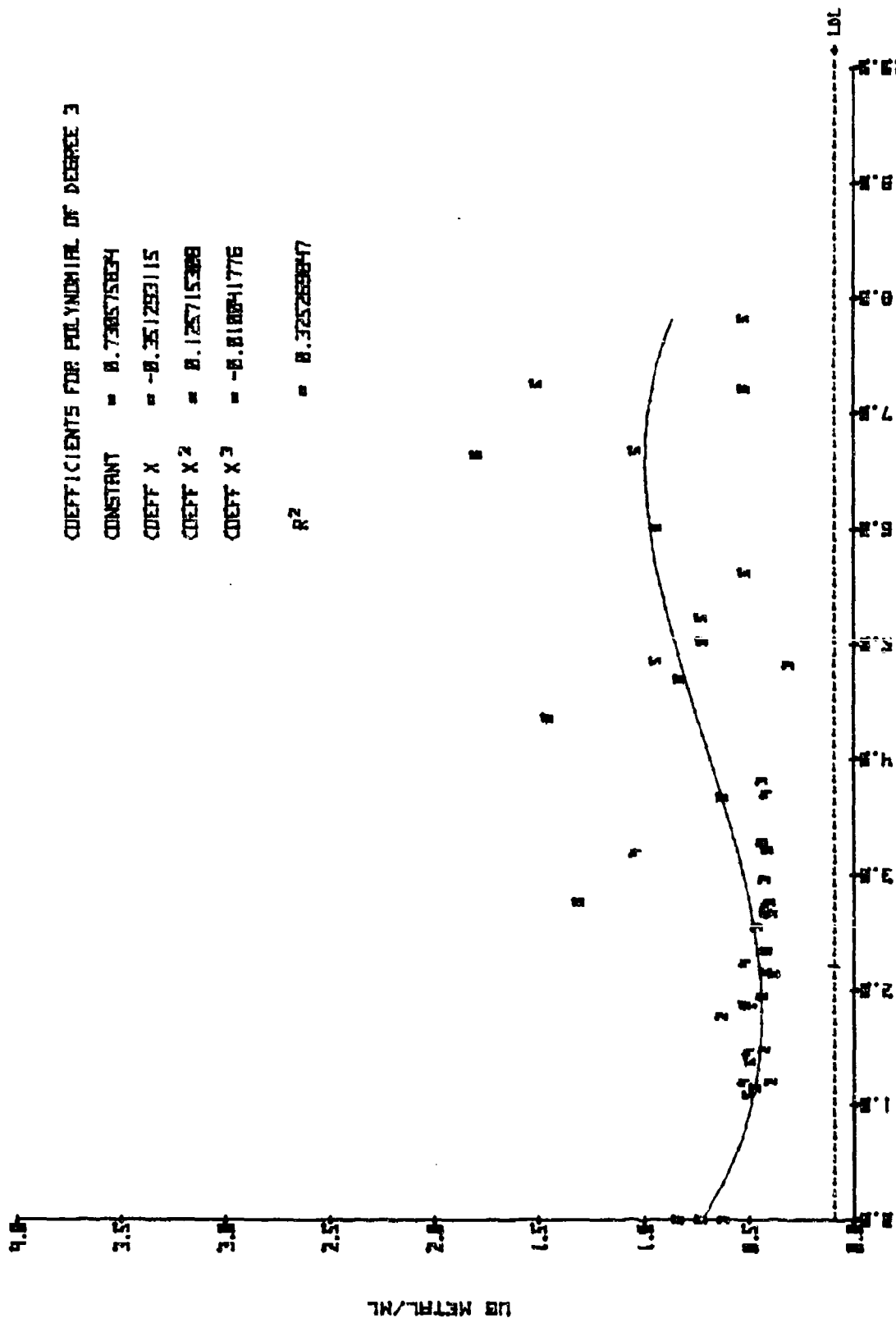
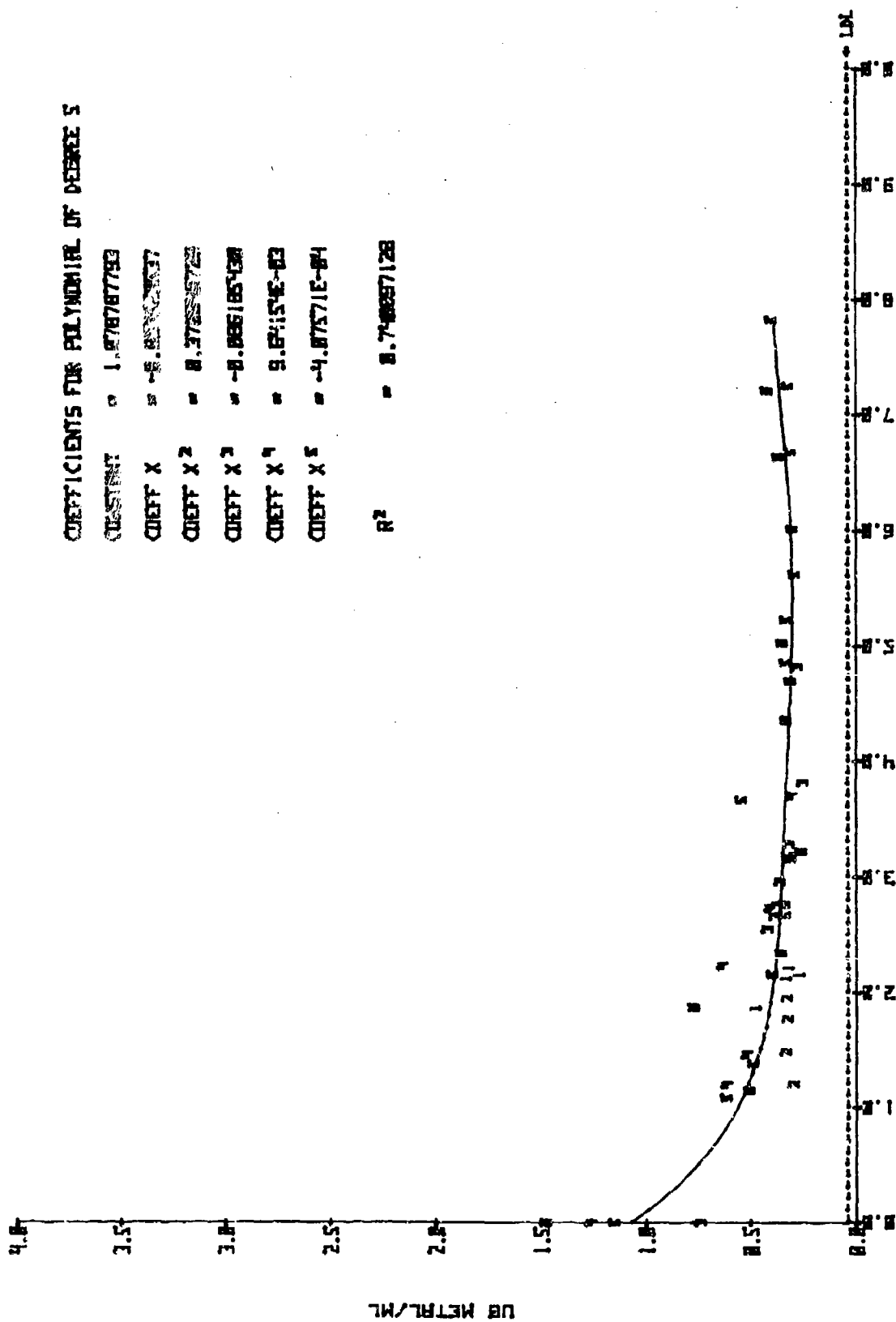


FIGURE 43: LEAD LEACHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 1.878787793
 COEFF X = -5.822222227
 COEFF X² = 0.372222222
 COEFF X³ = -0.006185438
 COEFF X⁴ = 9.64154E-03
 COEFF X⁵ = -4.87571E-04

R² = 0.748857128



CUM VOLUME (ML/GB)

FIGURE 4/4: NICKEL LERCHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

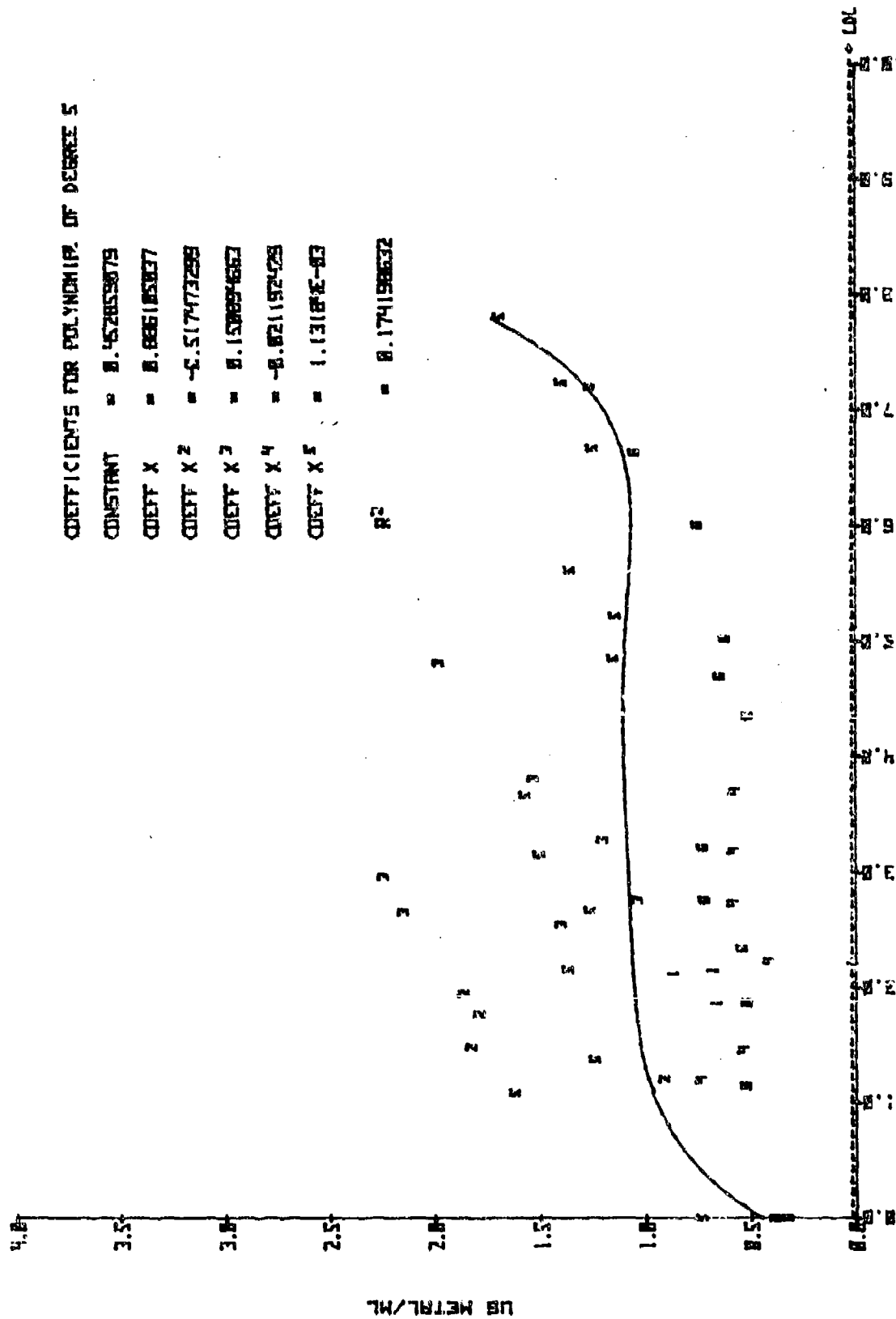


FIGURE 45: ZINC LEACHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

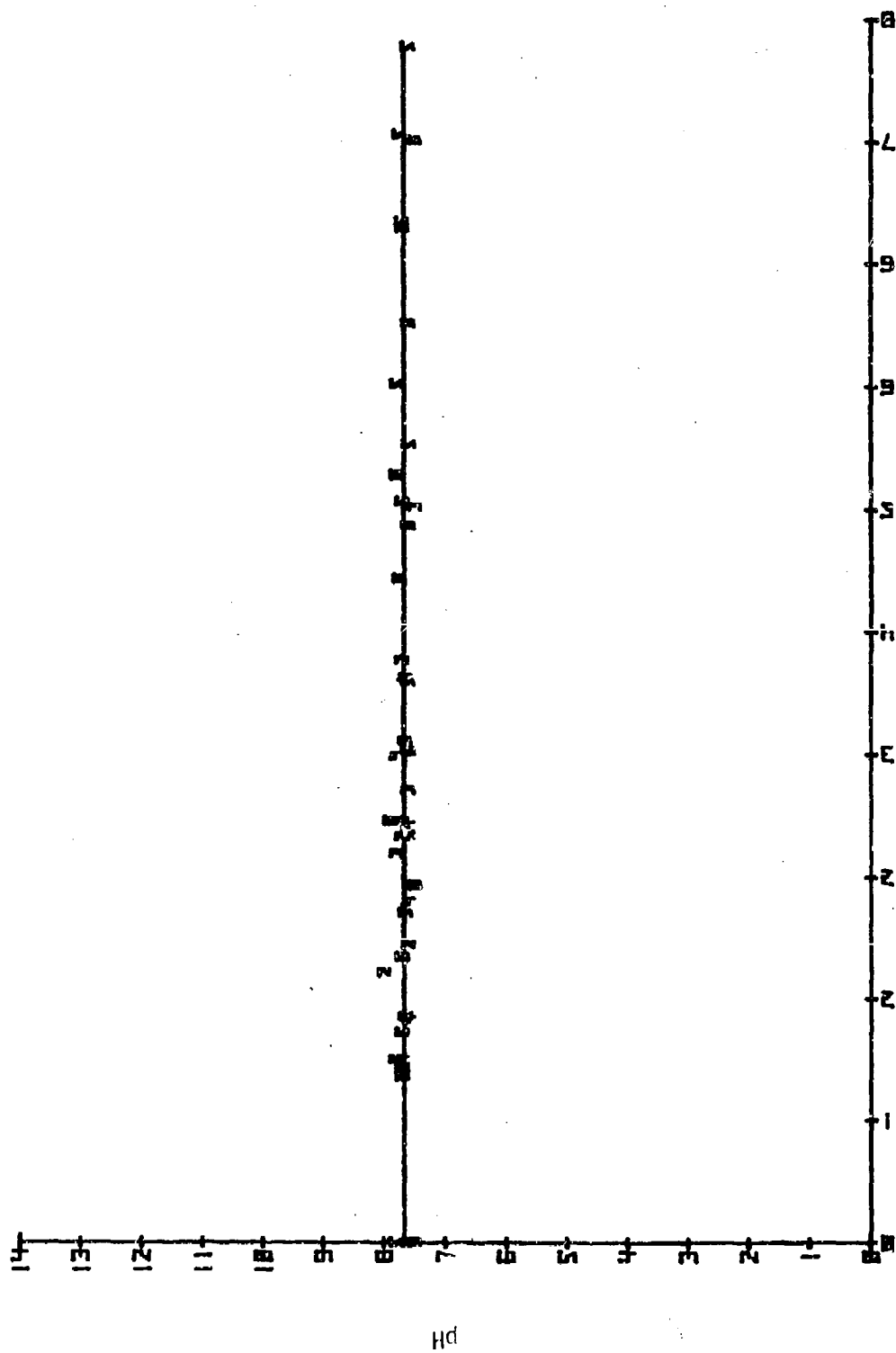


FIGURE 46: pH OF SOLUTION LEACHED FROM PIGMENT WASTE BY LANDFILL LEACHATE

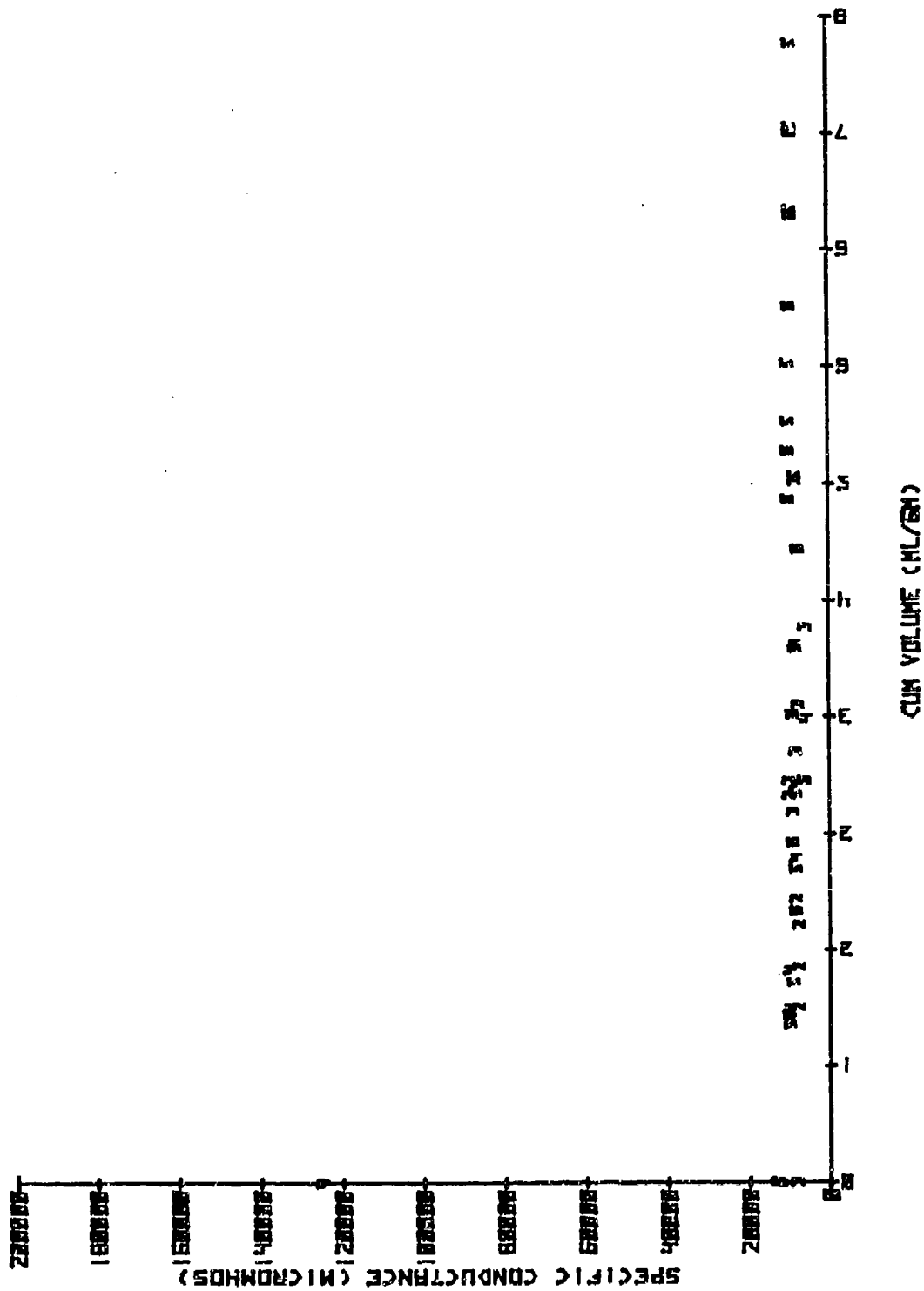


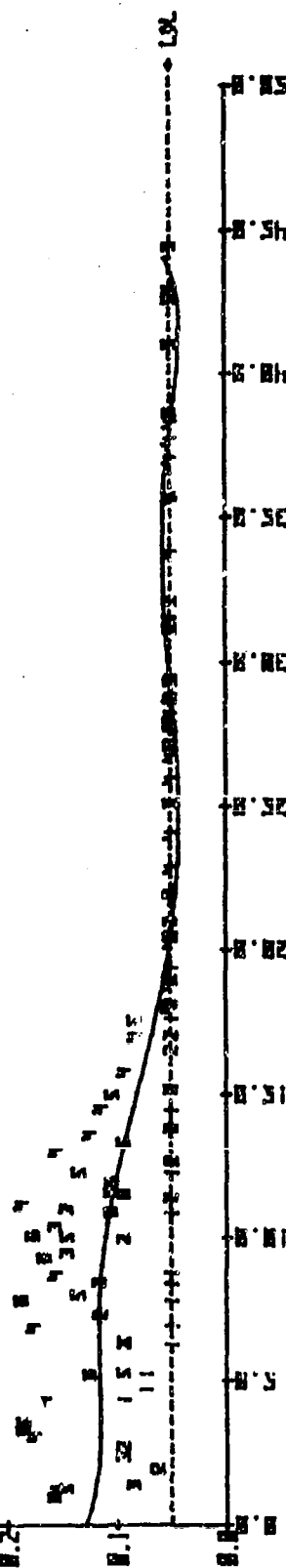
FIGURE 47: CONDUCTANCE OF SOLUTION LEACHED FROM PIGMENT
WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.128181925
 COEFF X = -0.018758633
 COEFF X² = 3.88849E-03
 COEFF X³ = -3.46538E-04
 COEFF X⁴ = 1.68516E-05
 COEFF X⁵ = -3.34538E-07
 COEFF X⁶ = 2.56633E-09

R² = 0.947279312

UG METAL/ML



CUR VOLUME (ML/BA)

FIGURE 48: CHROMIUM LEACHED FROM PRINT WASTE BY WATER

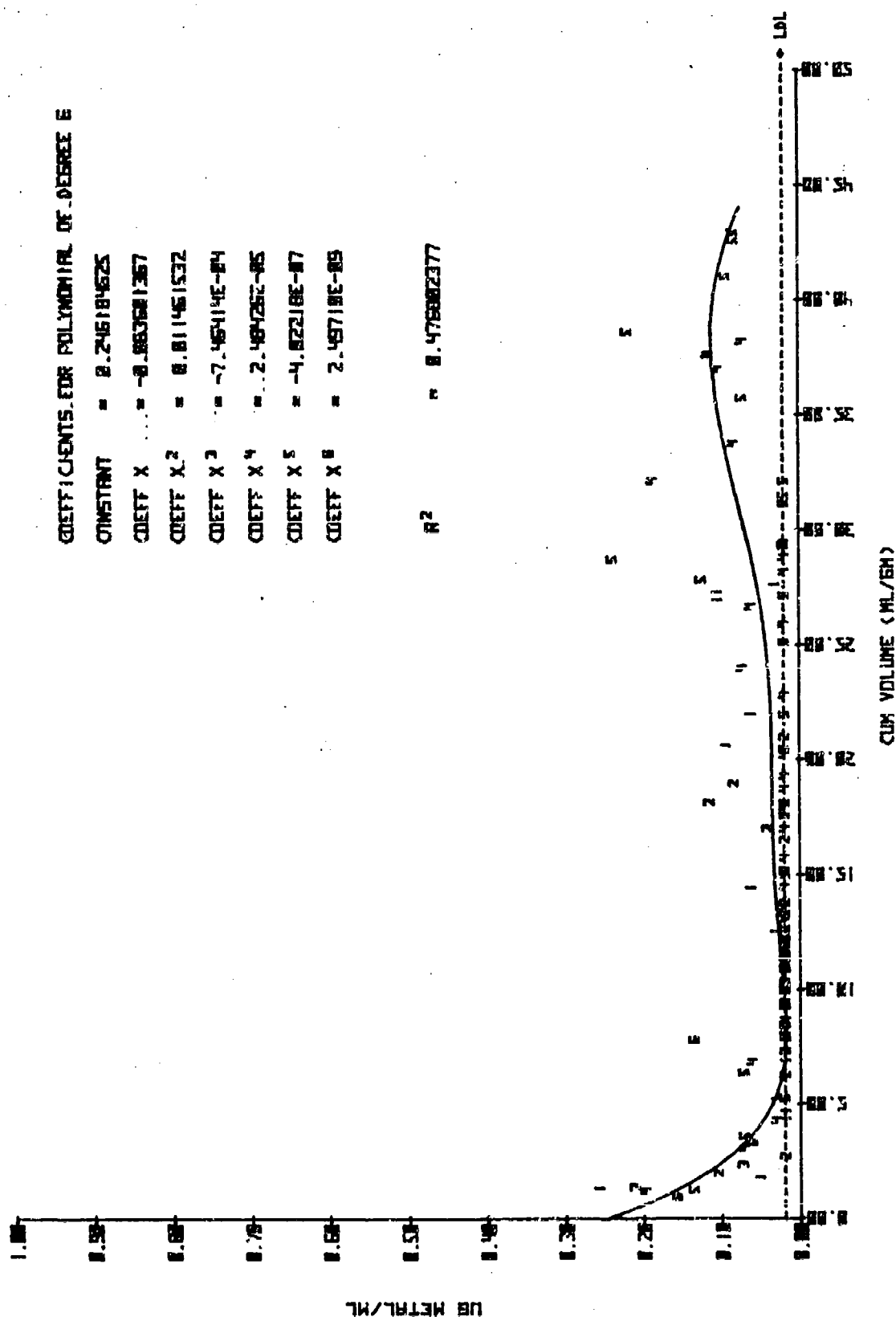


FIGURE 49: COPPER LEACHED FROM PAINT WASTE BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 0.738557902

COEFF X = -0.261822698

COEFF X² = 0.038483348

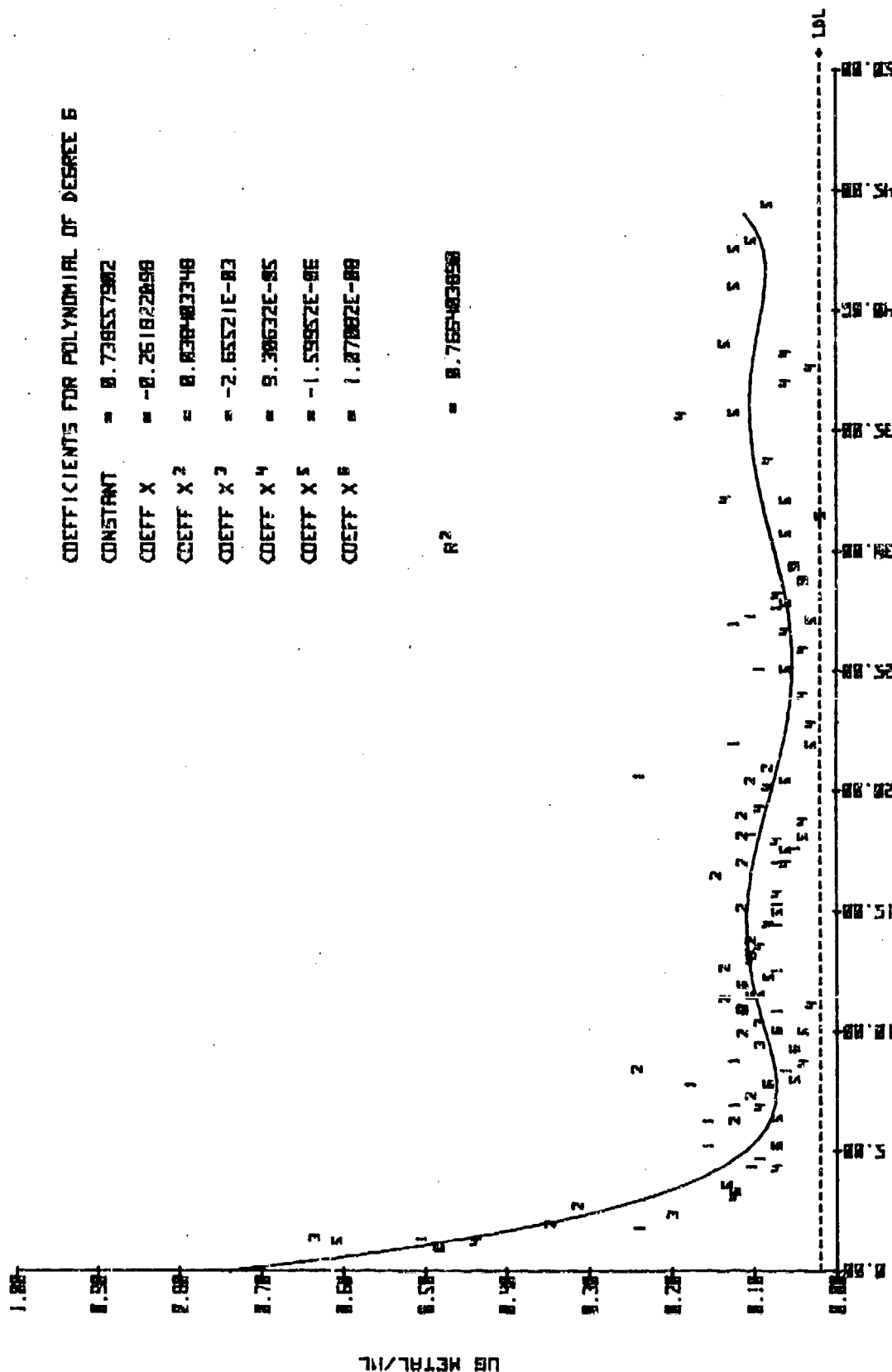
COEFF X³ = -2.65521E-03

COEFF X⁴ = 9.38632E-05

COEFF X⁵ = -1.59852E-06

COEFF X⁶ = 1.07882E-08

R² = 0.765483858



CUM VOLUME (ML/GM)

FIGURE 50: ZINC LACHED FROM PRINT WASTE BY WATER

Figures 51 and 52 are plots of pH and specific conductance values found in the waste leachate samples. The average pH started at pH8 and slowly decreased to slightly above 7 as the leaching continued. It was determined that the water base paint waste was the least soluble of the wastes. The specific conductance started at approximately 2,900 micromhos but rapidly decreased to approximately 200. This indicates that the waste contains little soluble material.

Landfill Leachate--

Figures 53 through 59 are pooled plots of cadmium, chromium, copper, lead, mercury, nickel and zinc concentrations leached by municipal landfill leachate from water base paint waste. The plots show that municipal landfill leachate solubilized rather remarkable quantities of these metals, particularly zinc, from the waste as compared to water.

Zinc was leached from the waste in the largest quantity and exceeded that found for water leaching over 300 times (575 micrograms/gram total). In addition, concentrations in excess of 200 micrograms/milliliter were found in individual waste leachate samples. This is over 40 times the drinking water standard.

Lead was leached from the waste (2.1 micrograms/gram waste). It was consistently found in the landfill leachate samples, compared to the water leachate samples, where it was found only sporadically. It also exceeded the drinking water standards in the landfill leachate samples.

Cadmium was found at levels exceeding drinking water standards in the waste leachate (1.1 micrograms/gram waste). Although the data is quite scattered, cadmium was found in substantial concentrations in the samples and is therefore ranked next as a potential hazard. It was found sporadically in the water leachate samples.

The weight of chromium leached was equivalent to that leached by water while the copper was less (0.9 micrograms/gram, and 0.2 micrograms/gram, respectively).

Figures 60 and 61 are plots of each pH and specific conductance of the individual waste-leachate samples. It is apparent that the water base paint waste had less effect upon the municipal landfill leachate compared to the other wastes. The initial pH of the waste leachate sample was 6.6. The pH gradually decreased to approximately 6.2 as the leaching continued. The pH of the landfill leachate before its addition to the waste column was 5.4 and 5.5. The specific conductance also indicates little material was solubilized from the waste. The initial specific conductance was approximately 9,000 but decreased to less than 8,000 micromhos.

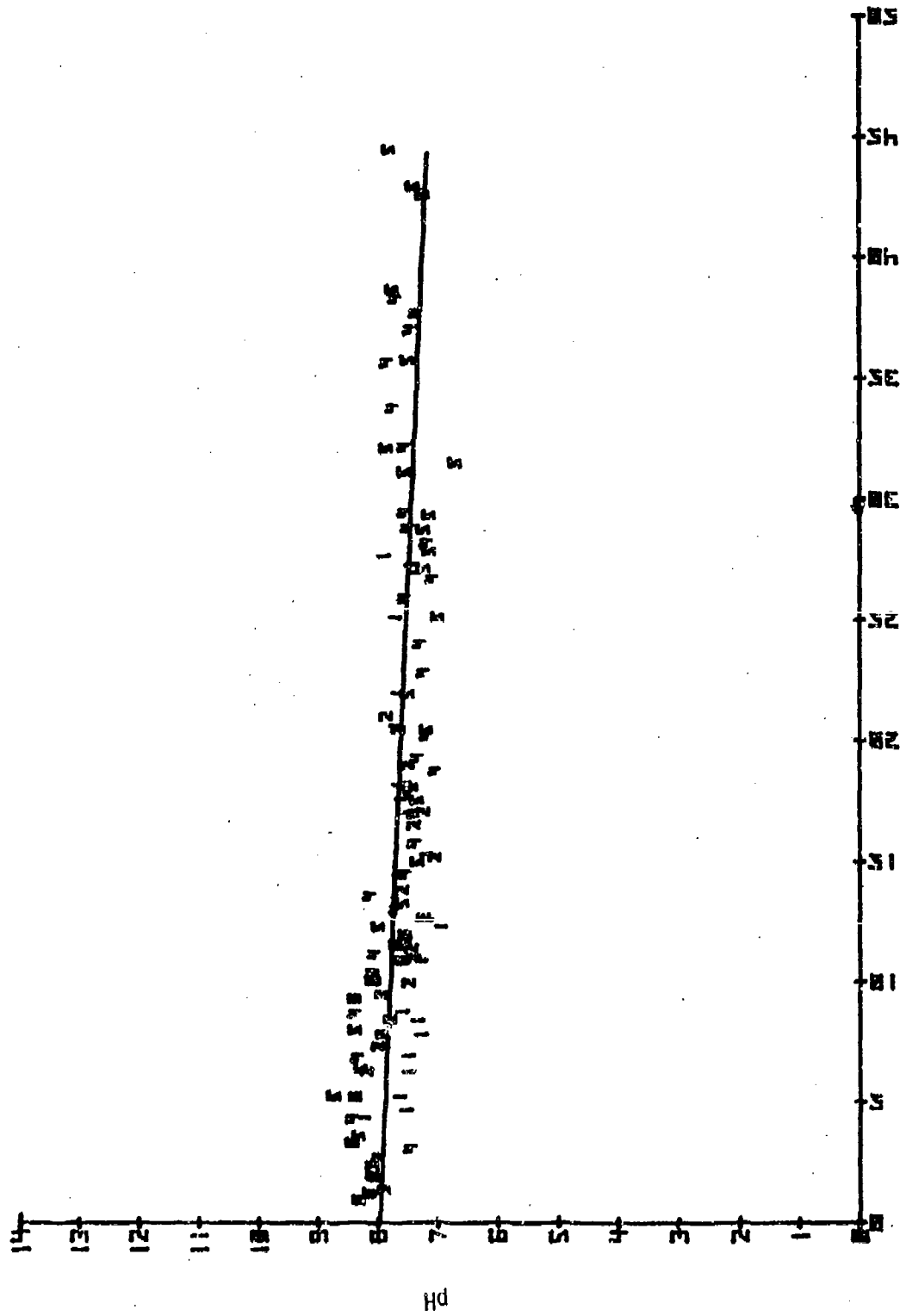


FIGURE 51: pH OF SOLUTION LEACHED FROM PAINT WASTE BY WATER

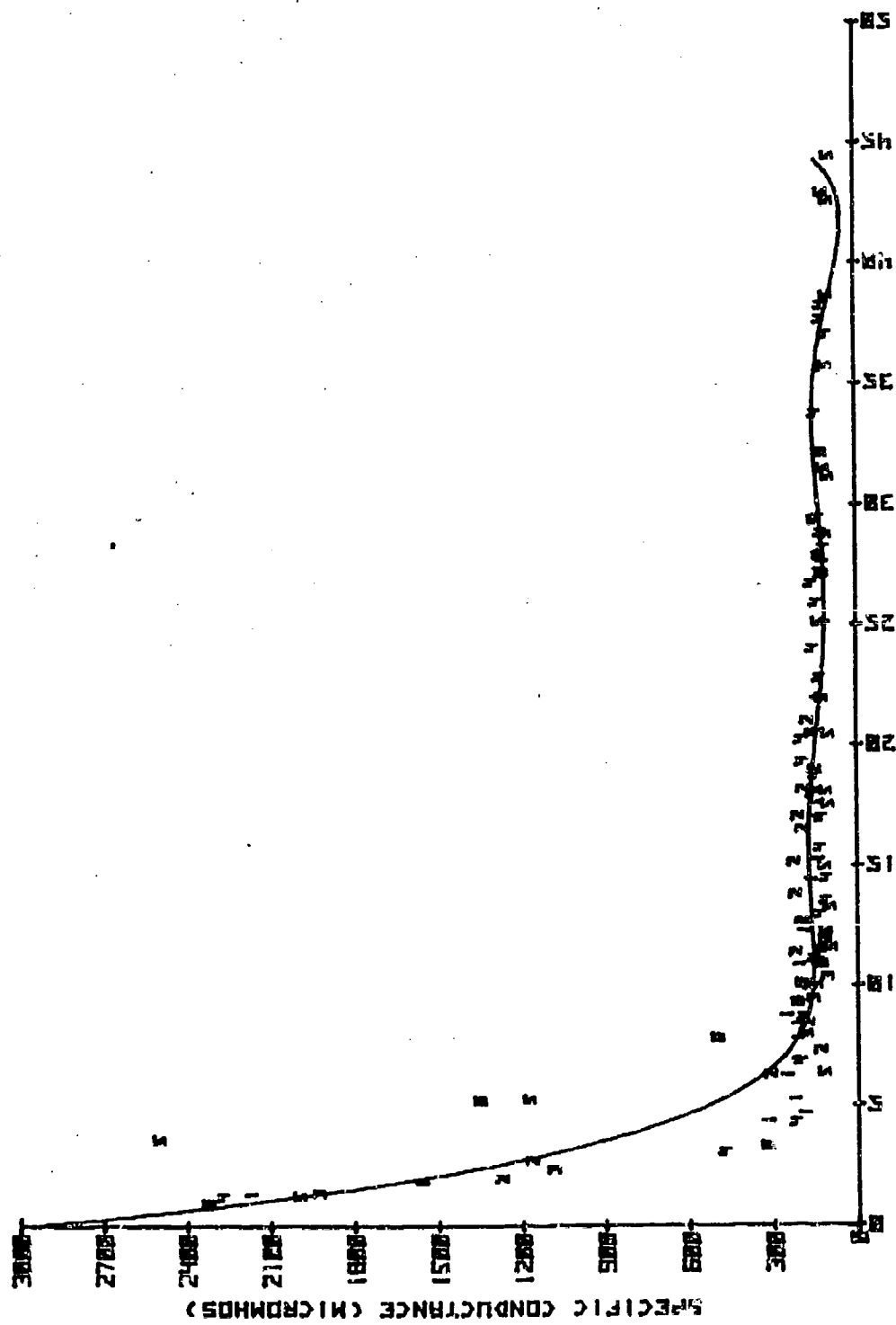
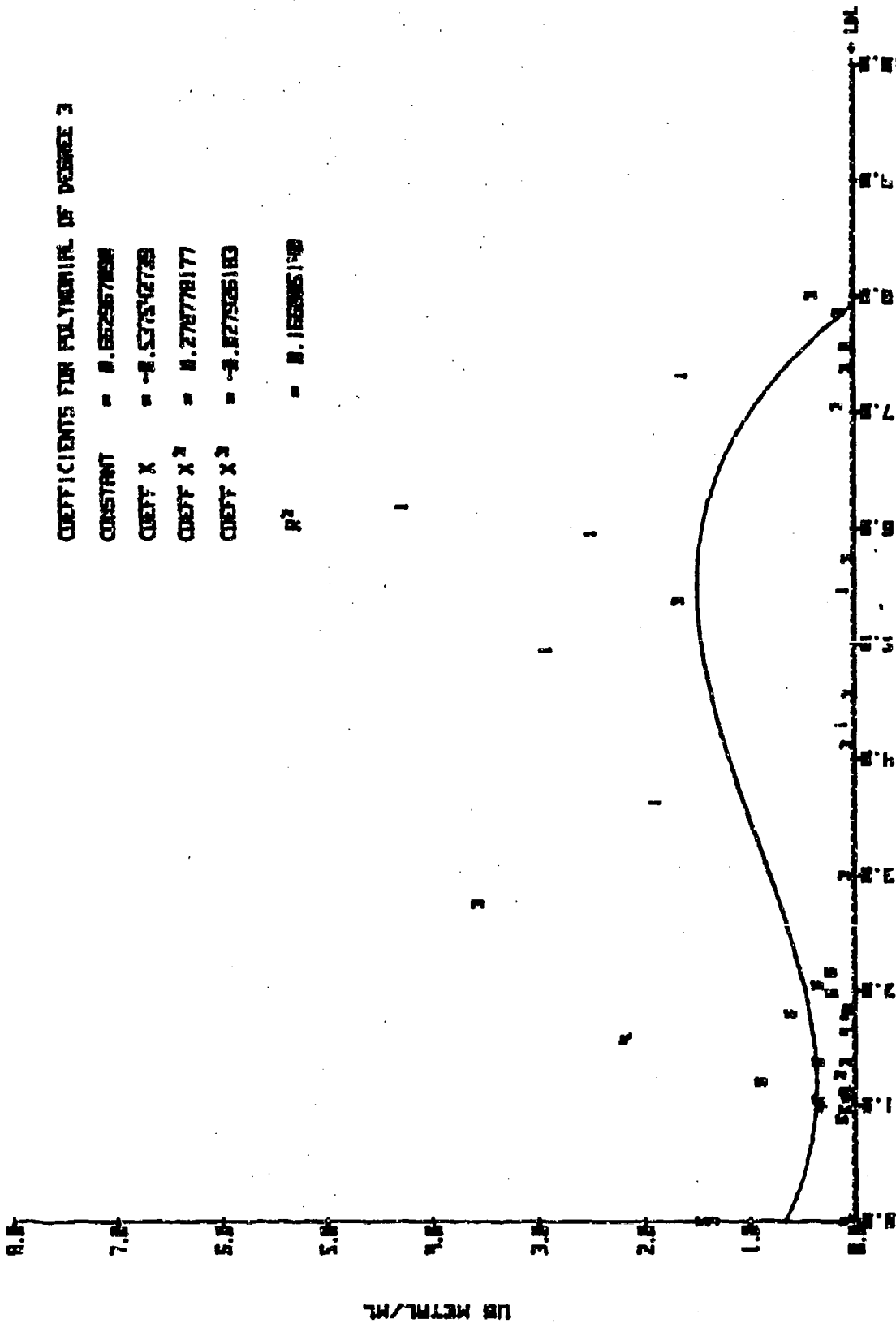


FIGURE 52: CONDUCTANCE OF SOLUTION LEACHED FROM PRINT WASTE BY WATER



Urea Volume (ml/gm)

FIGURE 53: CHROMIUM LEACHED FROM PAINT WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

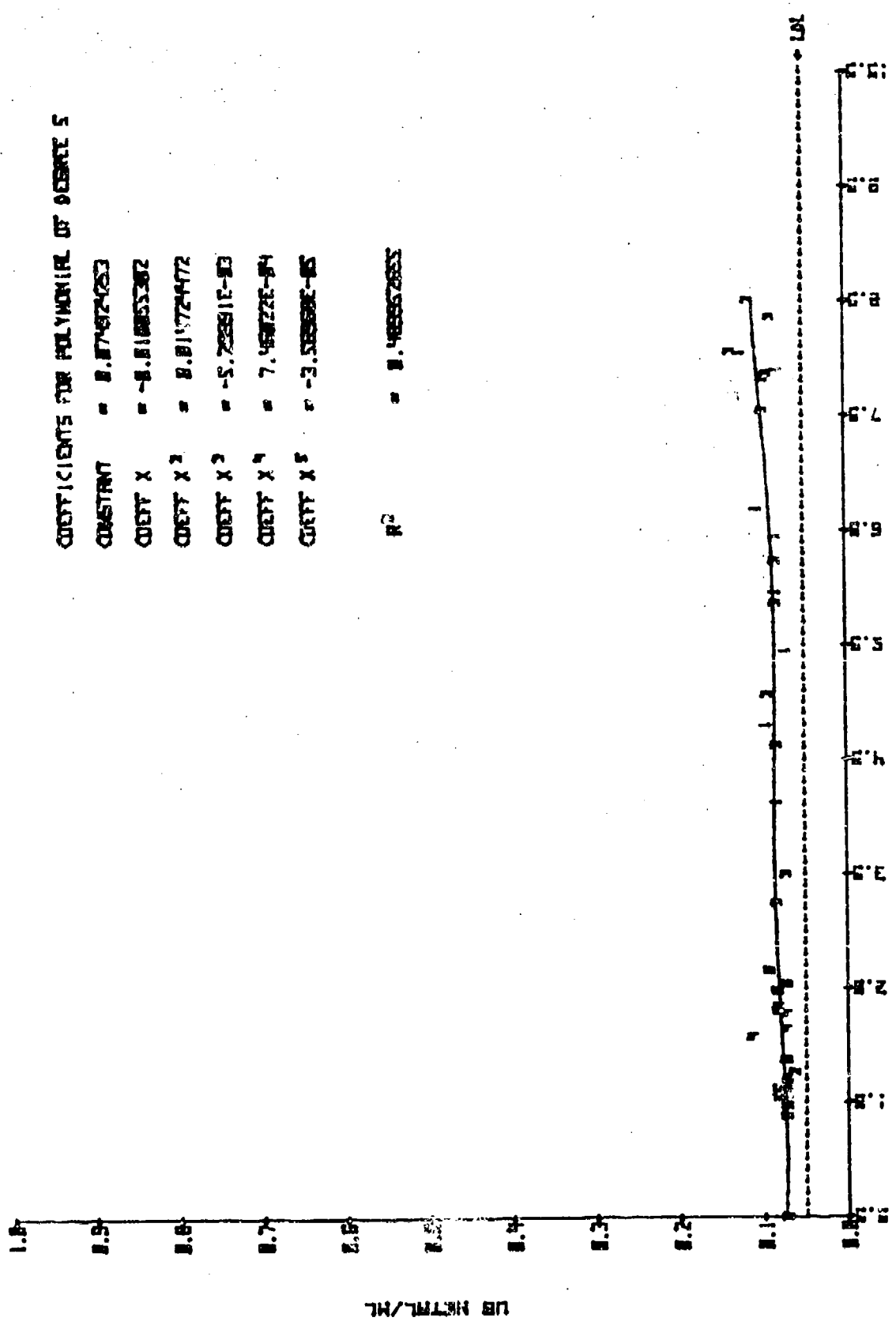
CONSTANT = 0.00296789

COEFF X = -0.537542739

COEFF X² = 0.278778177

COEFF X³ = -0.027526183

R² = 0.168865148



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 8.874824253

COEFF X = -8.818853872

COEFF X² = 8.811724472

COEFF X³ = -5.723311E-03

COEFF X⁴ = 7.458722E-04

COEFF X⁵ = -3.55555E-05

R² = 0.48552853

CUM VOLUME (ML/GH)

FIGURE 54: CHROMIUM LETCHED FROM PAINT WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 4

CONSTANT = 8.237749853
 COEFF X = -8.852811744
 COEFF X² = 8.831483888
 COEFF X³ = -5.888888889
 COEFF X⁴ = 4.216388889

R² = 0.988888889

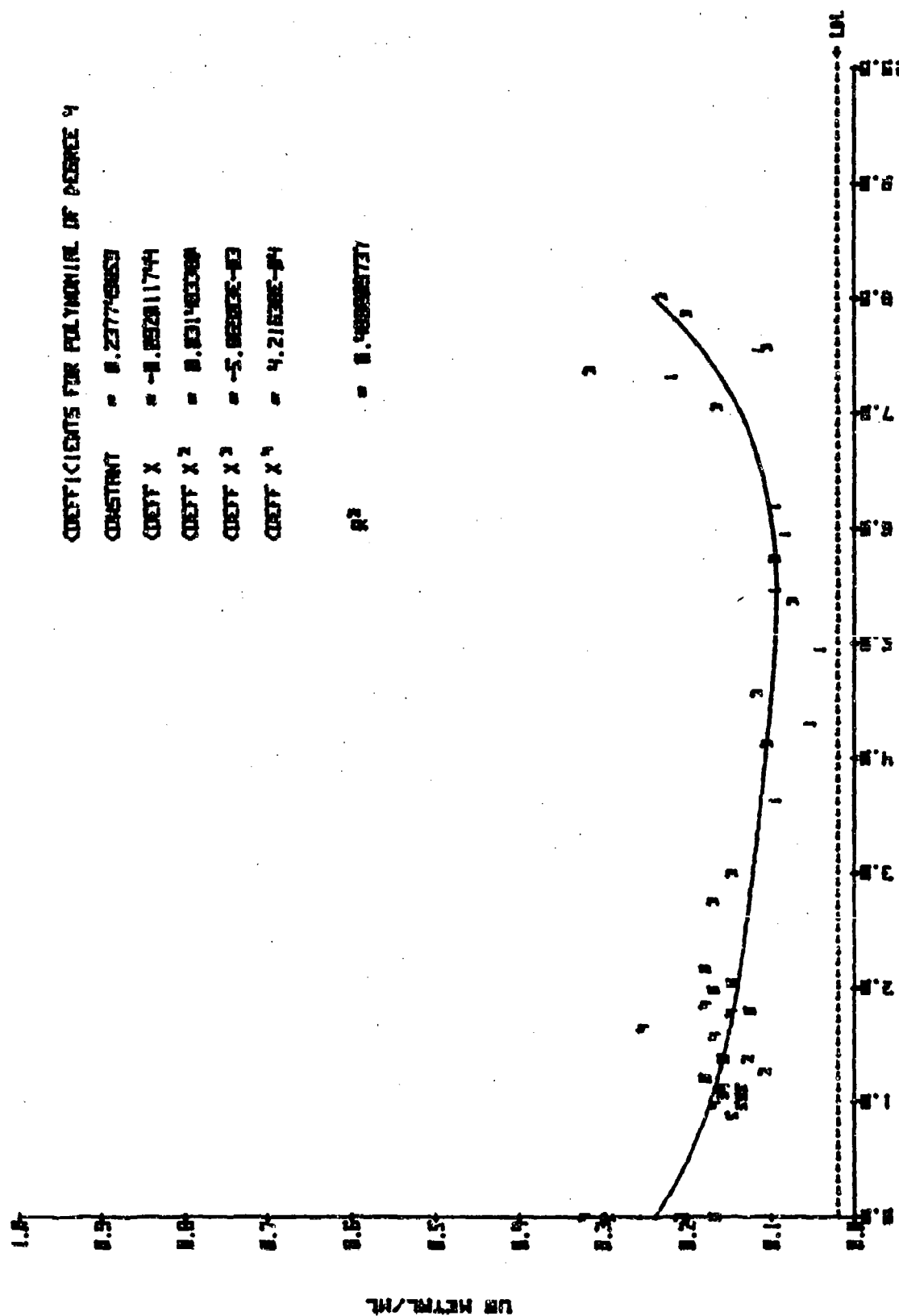


FIGURE 55: COPPER LETCHED FROM PAINT WASTE BY LANDFILL LEACHATE

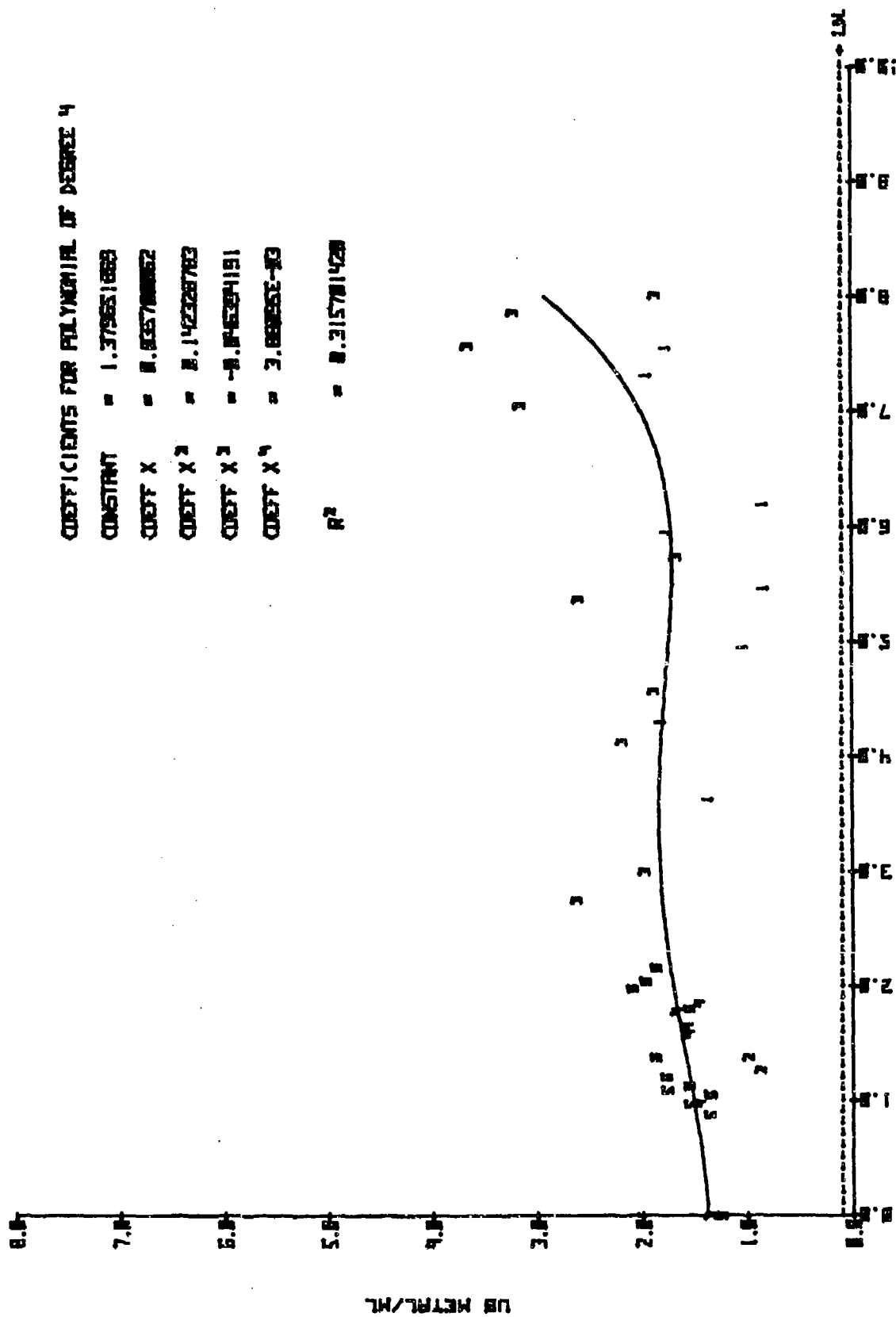
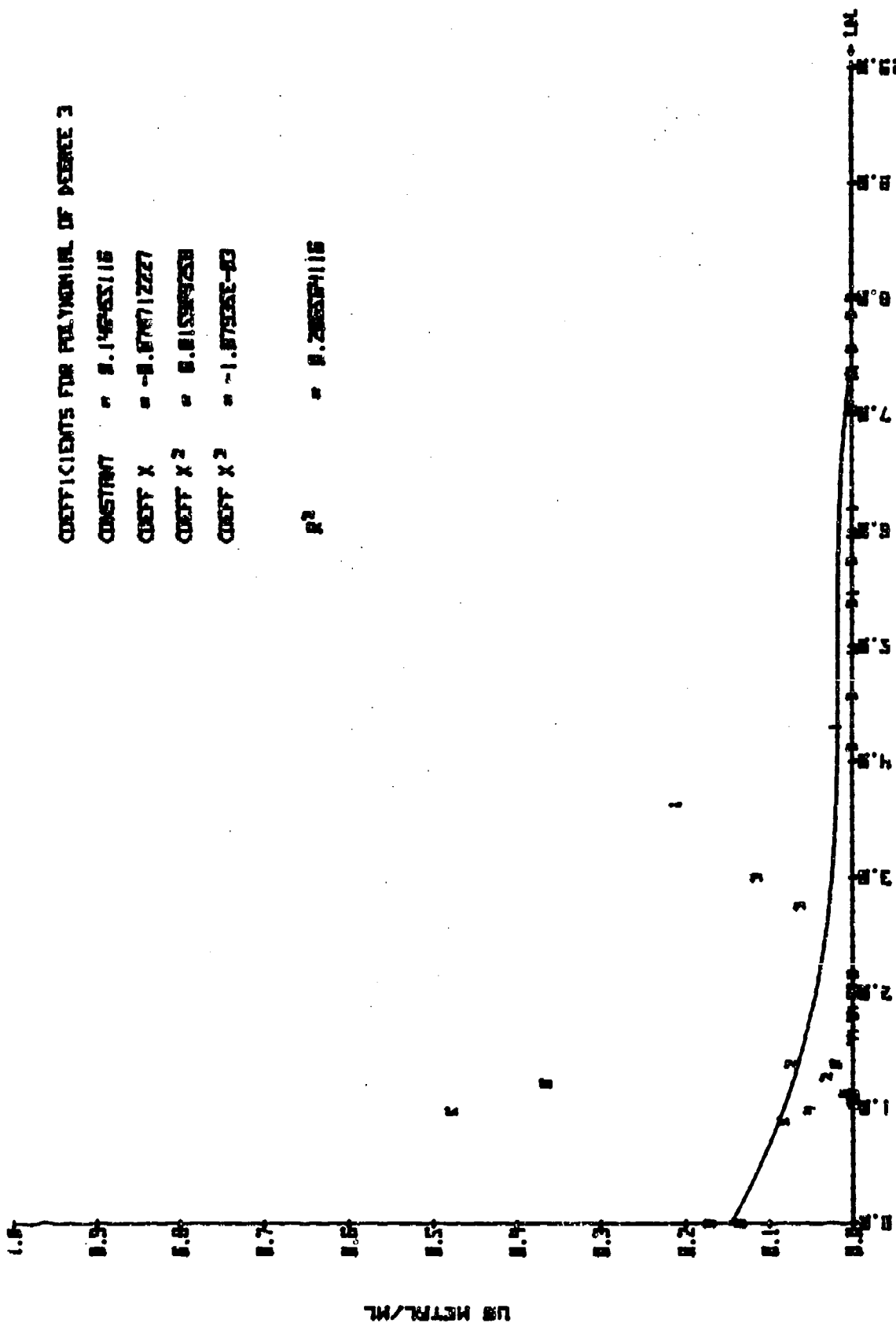


FIGURE 55: LEAD LEACHED FROM PAINT WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

CONSTANT = 0.146453116
 COEFF X = -0.076712227
 COEFF X² = 0.015897238
 COEFF X³ = -1.07935E-03

R² = 0.28554116



CON VOLUME (ML/EN)

FIGURE 57: MERCURY LEACHED FROM PRINT WASTE BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

CONSTANT = 8.282724411

COEFF X = -2.846794461

COEFF X² = 9.92518E-03

COEFF X³ = -5.84867E-04

R² = 0.374863276

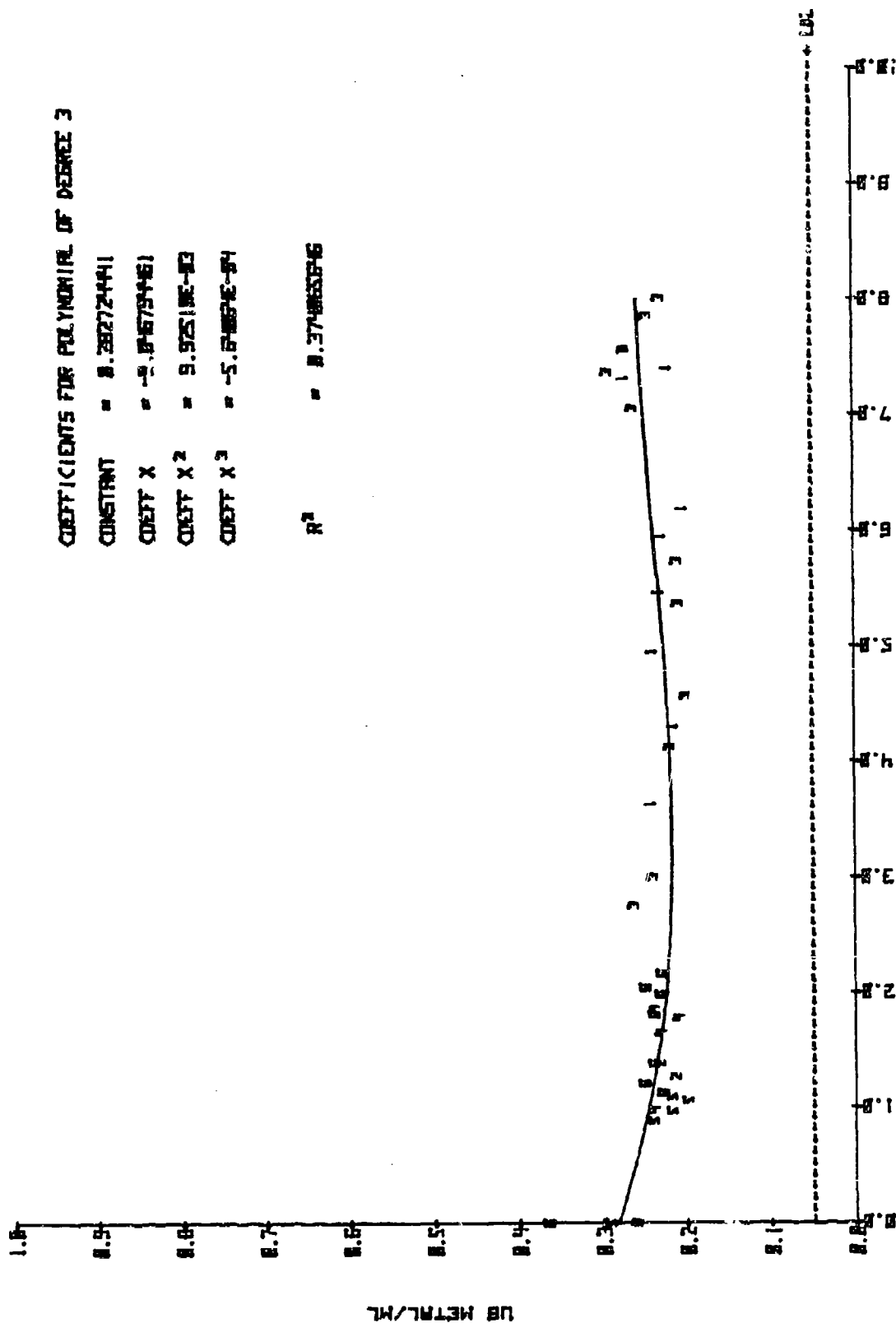


FIGURE 5B: NICKEL LEACHED FROM PAINT WASTE BY LANDFILL LERCHATE

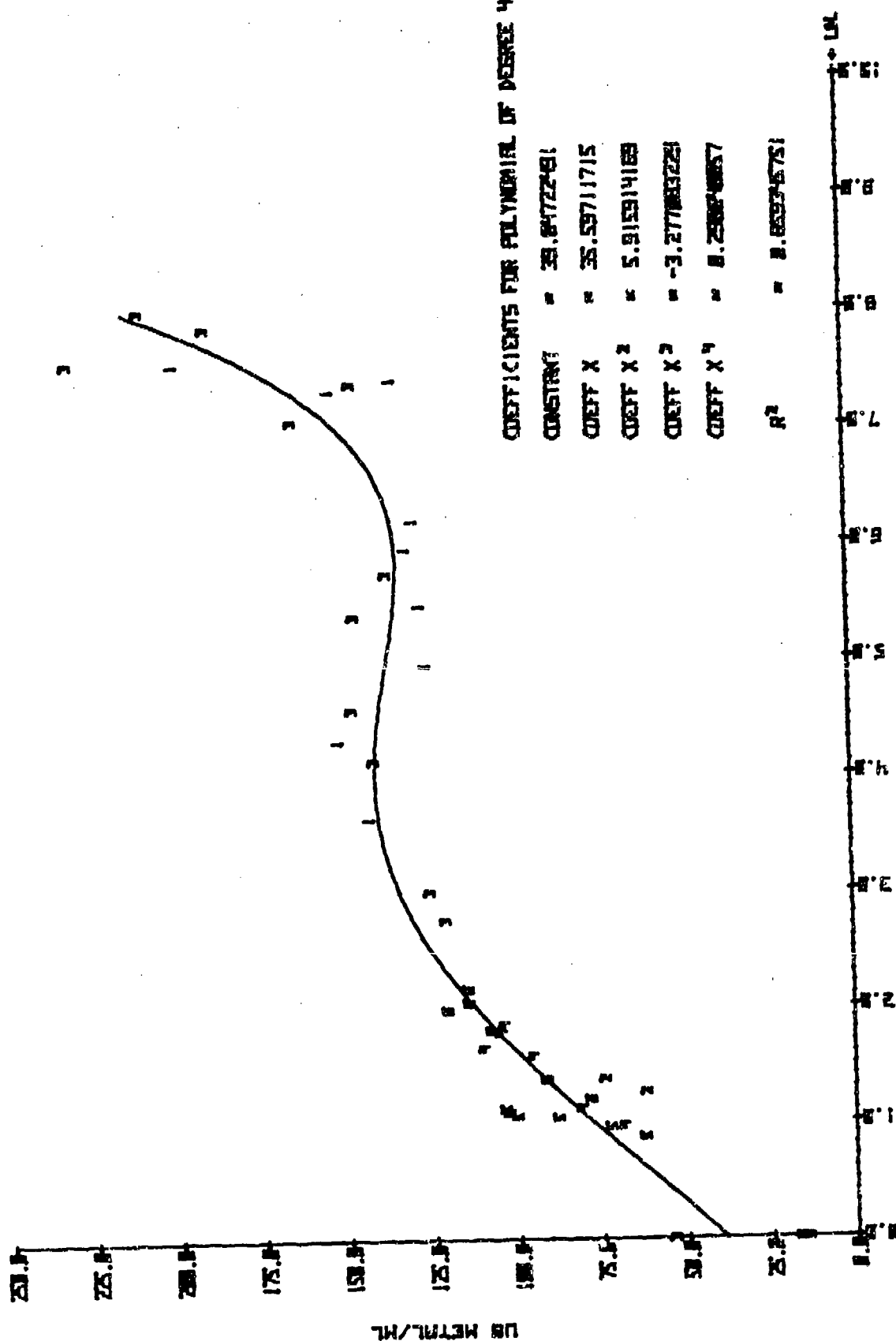


FIGURE 59: ZINC LEACHED FROM PRINT WASTE BY LANDFILL LEACHATE

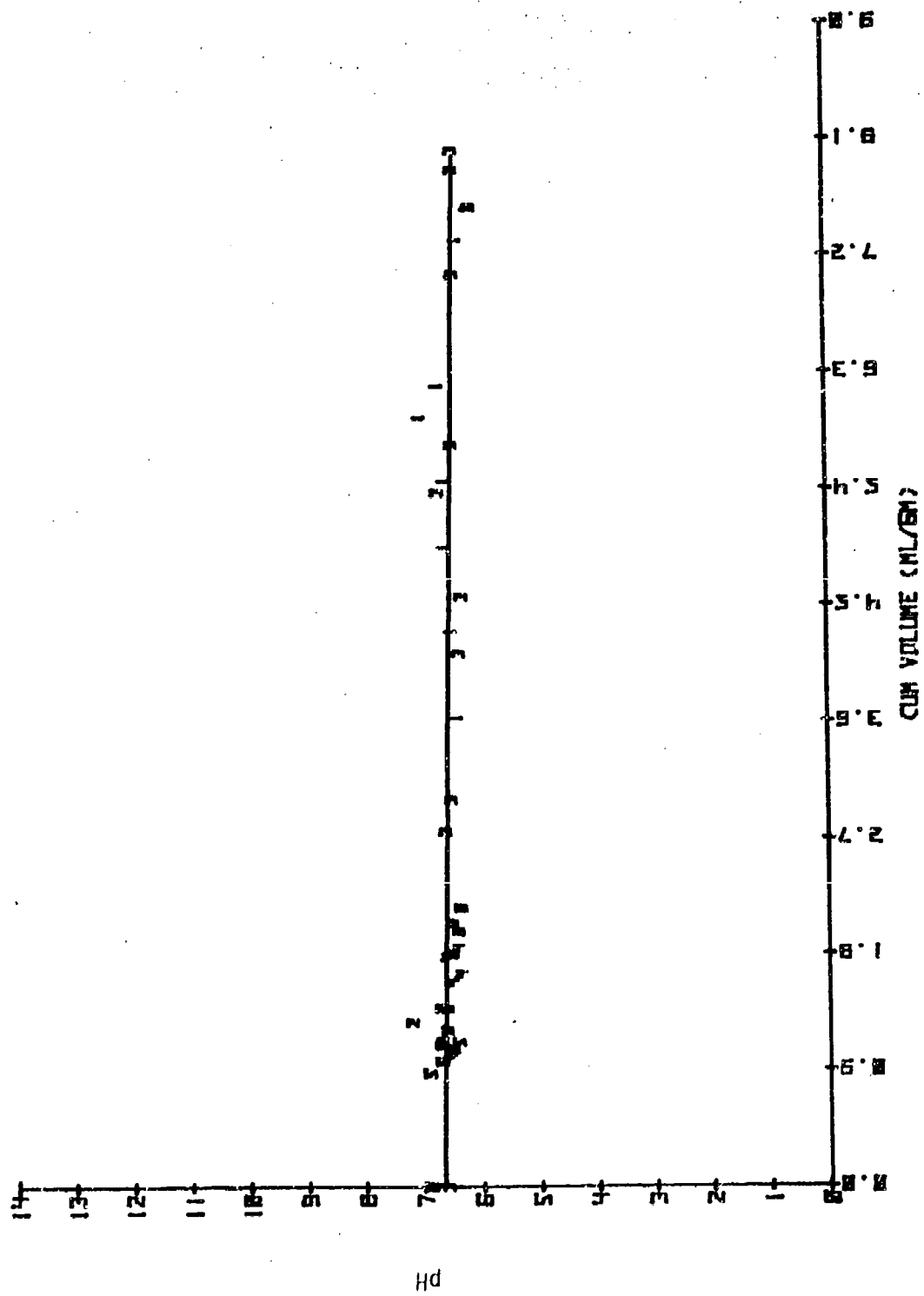


FIGURE 60: pH OF SOLUTION LEACHED FROM PRINT WASTE BY LANDFILL LEACHATE

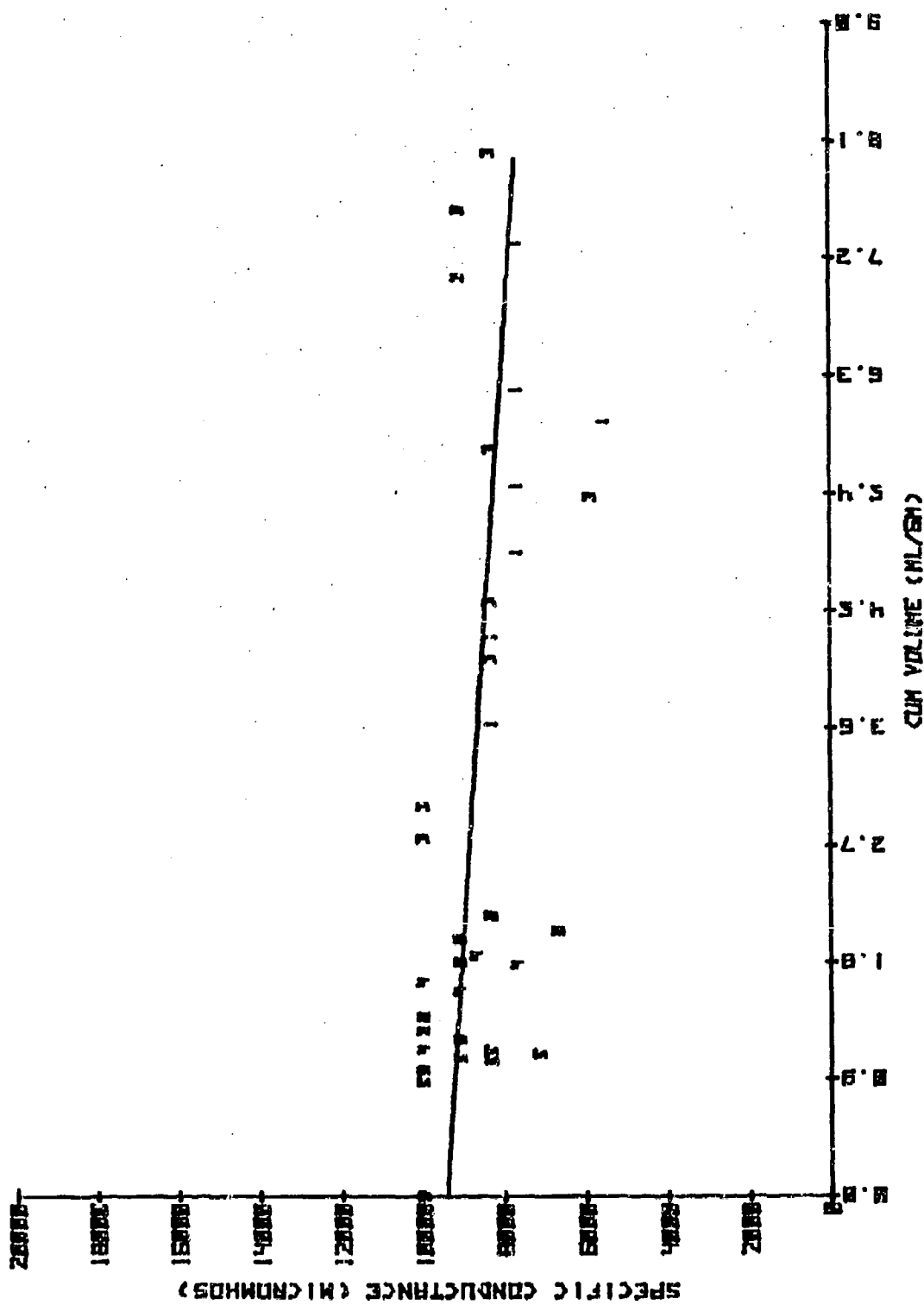


FIGURE 61: CONDUCTANCE OF SOLUTION LEACHED FROM PAINT
WASTE BY LANDFILL LEACHATE

Chlorine Production Brine Waste

Mercury is the species of interest in this waste. Mercury was rarely found in waste leachate samples whether water or municipal landfill leachate was used as leaching solvent. It was suspected that the mercury was leached at concentrations below the detection limit of the analytical method (0.0002 microgram/milliliter). This was the case when the soil columns were sectioned and analyzed. This will be discussed in more detail in a subsequent report.

PREDICTING WASTE LEACHING BEHAVIOR WITH BATCH TESTS

Introduction

This portion of the report is devoted to preliminary comparisons of batch extraction and continuous column extraction as methods for predicting the leaching behavior of wastes. Many similarities in the leaching of metals from wastes were noted, regardless of the leaching technique used. This suggested that the column studies might eventually be replaced by batch studies, saving time and expense without sacrificing quality of the information gathered. In the following paragraphs, a batch procedure for studying the leaching behavior of wastes is described and the results of batch tests with electroplating waste are compared with the results of previous column tests on the same waste. The batch test appears satisfactory for the electroplating waste and likely for the other four wastes used in this project. It should be noted that all five of these wastes are granular materials with a low content of organic matter. It is recognized that the batch test described below may have to be modified to be useful with organic wastes, particularly with those that are oily or amorphous.

Tentative Leaching Test

Sample Preparation--

Before portions of waste are removed for the batch testing, the sample must be well mixed. Settling under vibration during transportation may cause sorting and differentiation of the waste particles. If there are two phases or states of subdivision (e.g., chunks or large crystals in a sludge or powder) which cannot be mixed well enough to take a valid sample, it may be desirable to test them separately.

To avoid dehydrating components (such as gels and hydrated forms) to materials that may be more difficult to dissolve, do not heat the waste above what it would be subjected to at the disposal site (normally sun-drying in air). Do not dry the waste at all if it will remain moist in the field. Instead, determine the moisture content on a separate sample to allow calculating the dry weight and the initial amount of water present, and adjust the test sample size accordingly. The internal and supernatant water can be considered to constitute the first batch

of extract. This can be filtered off (later measuring its volume and analyzing it for metals, etc.) and another portion of water or landfill leachate added as discussed below.

Batchwise Serial Extraction Procedure--

Weight duplicate waste samples into Erlenmeyer flasks, allowing for the moisture content if necessary. (We used 20 grams dry weight.) Add water, or landfill leachate, in the proportion of 2 milliliters per gram of waste (i.e., 40 milliliters). A small water-to-waste ratio is desirable at first to remove the readily soluble components without too great a dilution, which could change the salt concentration and ionic strength, conceivably affecting the solubility of other components. Shake the flask four or five times during the workday. Continual mechanical shaking may abrade the particles of waste, making them more susceptible to extraction. The next day, shake again, let settle, and filter with a vacuum through a Buchner funnel. (Some wastes may require longer than a day to reach equilibrium. This can be checked by withdrawing aliquots for analysis each 24 hours until no further concentration increase is seen.) Filter the filtrate again through a fine millipore filter to remove all suspended materials (because they will give erroneously high values) and analyze the solution to determine the concentrations of materials of interest. Transfer the residue from the filtration back to the flask, add a second portion of water (e.g., 3 milliliters per gram of waste), shake again over about 24 hours, and filter. Repeat the process with additional successive portions of water. A series of extractions utilizing 2 milliliters of solvent per gram of waste, then 3 milliliters, 6 milliliters, 12 milliliters, 24 milliliters, and 48 milliliters per gram will require 7 working days to reach a cumulative extraction volume of 95 milliliters per gram of waste. (This is equivalent to about 7 months of continuous-flow column work.) Additional extractions, especially with much larger volumes, may be added to simulate even longer leaching periods. (Before deciding to increase the volume used in the next extraction, consider the lower detection limit that can be achieved and the concentration measured in the last extraction.) Each extract is analyzed to determine the concentrations of materials of interest. The observed concentrations may be plotted as histograms (against the cumulative extraction volume on the abscissa), and the areas of the sections will represent the total weights presented to the soil. Figure 62 illustrates this type of plot.

For even faster estimates of the yield of extractable species, larger proportions of solvent may be employed, although the shape of the leaching curve (as obtained from continuous column work) will be less accurately determined and there is a danger that a somewhat different solubility may be obtained. To obtain quick estimates (e.g., in 24 hours) of what would be leached even over protracted periods, several batches could be extracted simultaneously, using different solvent-to-waste ratios; for instance, 2, 50, and 200 milliliters per gram of waste. This would yield histogram shapes like those in Figure 63. These values could then be refined by performing two more extractions on the residue from the 2-milliliter-per-gram extract (which has had the bulk of the readily soluble components removed), using perhaps 40 milliliters per gram, and then 150 milliliters per gram, as illustrated in Figure 64.

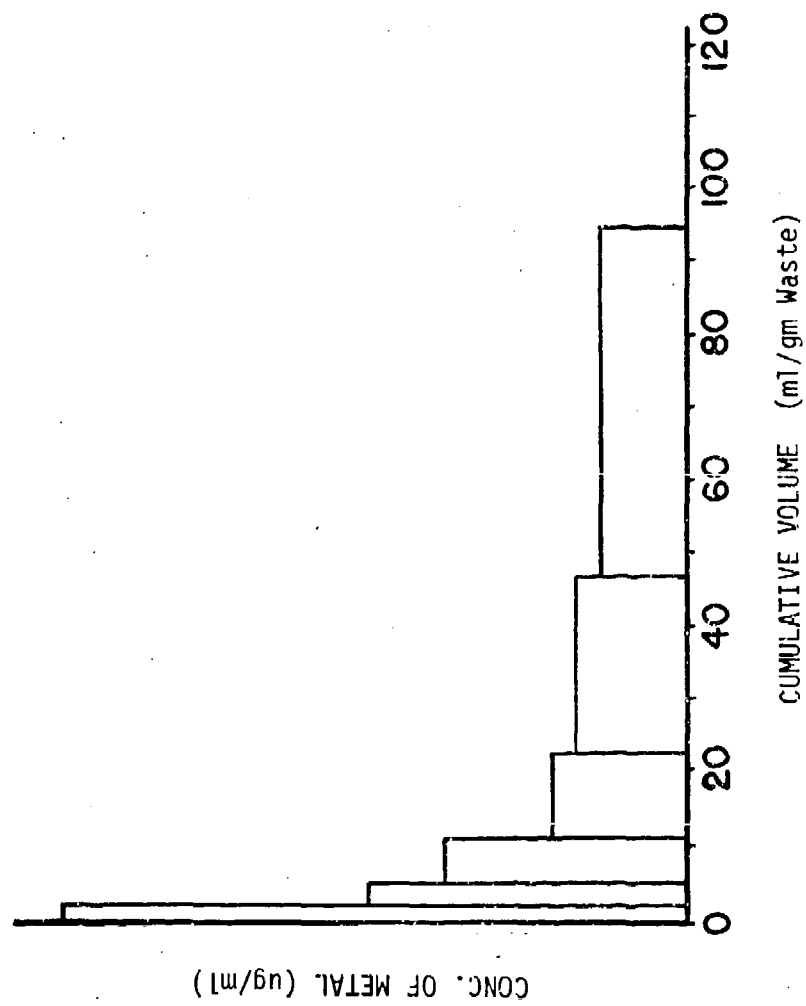


FIGURE 62: PLOTTING SERIAL BATCH EXTRACTIONS

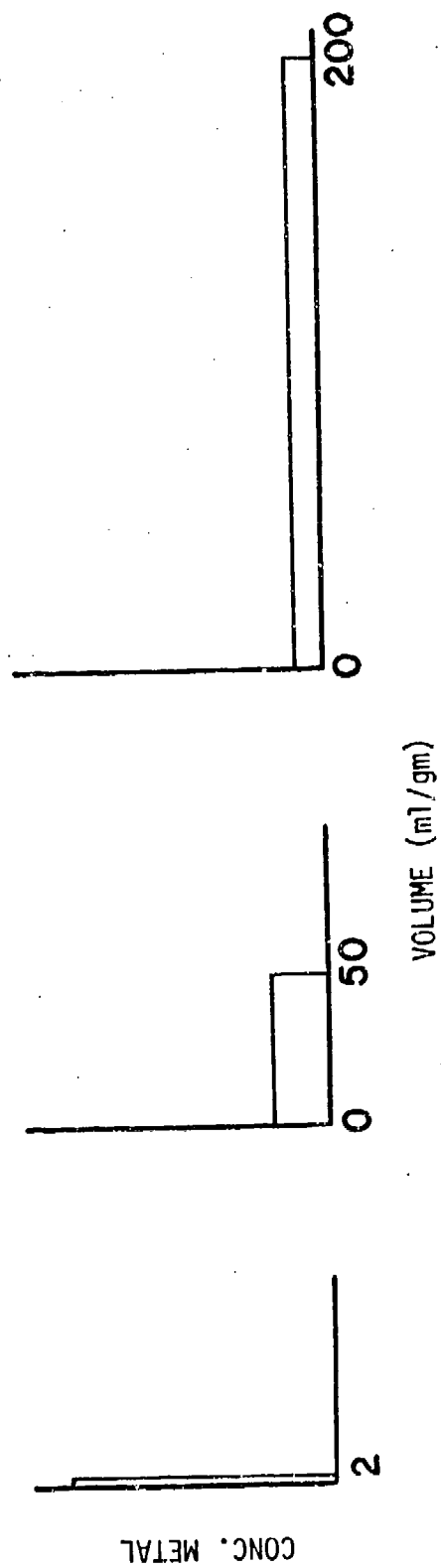


FIGURE 63: CONCURRENTLY RUN RAPID LEACHING TESTS

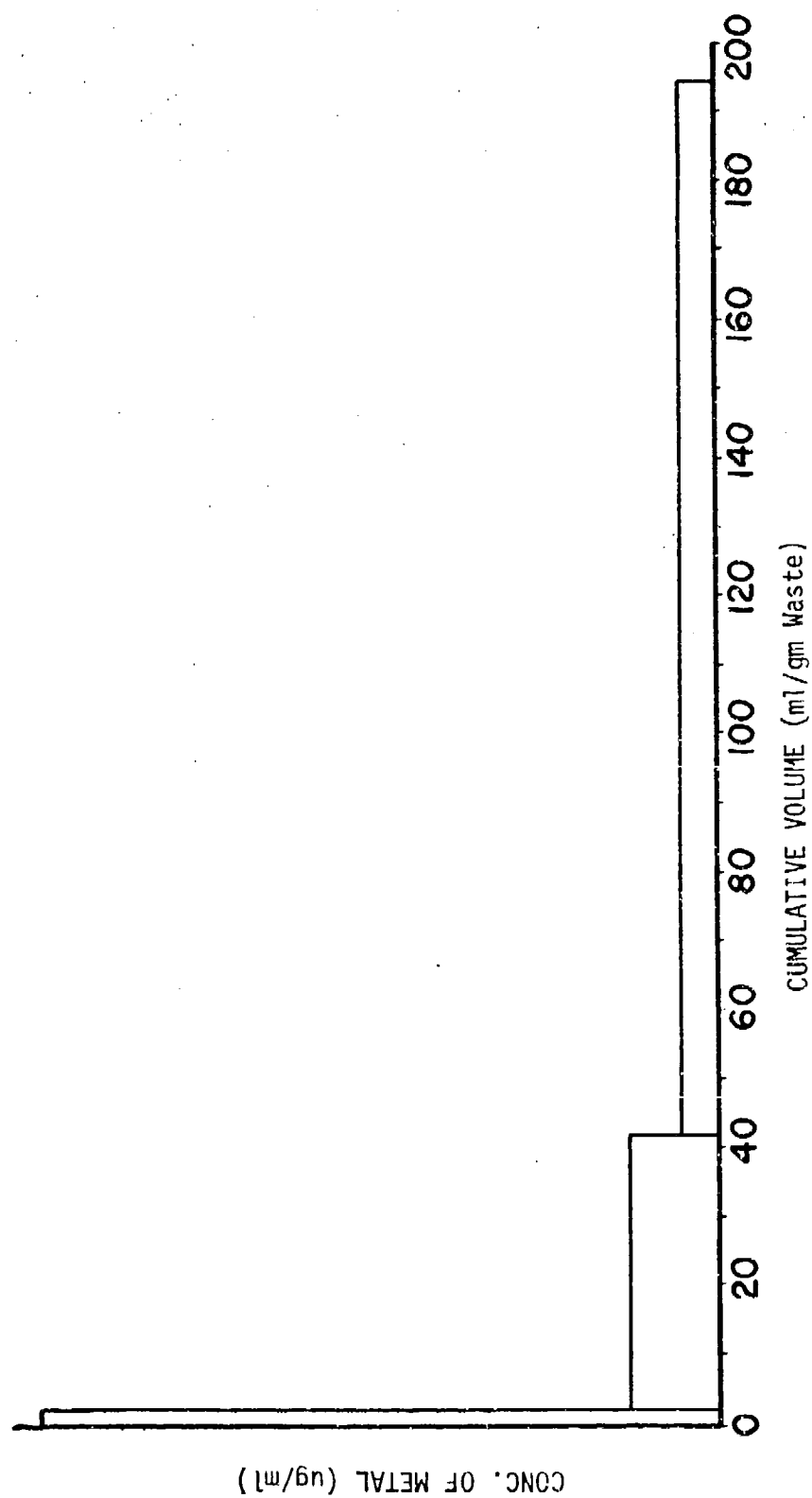


FIGURE 64: REFINING THE INITIAL RAPID ESTIMATE

Advantages of Batchwise Extractions

The much greater speed of evaluating wastes should be of particular value in checking the effect of changing a pre-treatment process, changing the waste stream composition, changing a step in the manufacturing process, or obtaining certification to dump a load of waste. The batch method also makes it easier to investigate a wide variety of additional variables. Samples can be included to test the effect of acid rain, of disposing of different kinds of wastes together, of simulated environmental conditions, of inserting drying or freezing cycles, etc. This ability to include controlled variables allows running the investigations as factorial experiments. Equations relating the significant variables and interactions can then be derived and used to make good predictions of leaching rates under sets of conditions that match given field situations.

Correlating Batch And Continuous Column Extractions

It should be evident that continuous column leaching is equivalent to running a series of incrementally spaced batches which are extracted with an amount of water barely above field saturation. Plotting the cumulative extraction or leaching volumes as milliliters per gram of waste, versus the observed concentration of each metal in the resulting solution, puts the results from both procedures on a common basis and allows correlation of the data. The validity of substituting batch tests for column test was checked by batch-testing the electroplating waste for which extensive continuous-column work had already been done. The batches, whose results are shown in Figures 65 through 68 as histograms, were only single samples so some deviation from the continuous leaching results (which are accepted as the standard) is evident. The continuous leaching curves used in Figures 65 through 68 are a repetition of the data shown in Figures 12 through 15; each curve represents the combined results from six columns. The fact that this batch work uses moisture contents substantially above that in the columns, but still correlates well, suggests that the batch procedure is an adequate substitute for continuous leaching over quite a wide range of moisture contents. The initial extraction purposely uses a reduced amount of water, because a dependence on dilution ratio is most likely here.

The areas under the histograms or curve segments give the total weight of metals extracted per gram of waste by that volume of water. The values can be used to estimate the total weight of a metal likely to be leached from any mass of waste.

METALS ANALYSIS AND QUALITY CONTROL

Atomic Absorption Spectrophotometry

A Perkin-Elmer Model 503 Atomic Absorption Spectrophotometer (AAS) was used to perform all metal analyses except mercury. Mercury was measured using a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer equipped with a flameless mercury attachment. The AAS equipment and operational parameters used for the determination of beryllium, cadmium, chromium,

copper, lead, mercury, nickel, and zinc are discussed below. The analytical detection limit given for each element is the weight of metal which produced a recorder response or readout twice the background noise. This is the detection limit selected for each metal in the soil or waste leachate.

It will be noted that a range is given for lower detection limits for some metals. This is due to the changing composition of the samples as the waste/soil columns are leached. The initial samples contained higher concentrations of salts than the later samples; this caused changes in the detection limits for some metals. Also, small differences in instrumental settings, different operators, and aging of the hollow cathode or electrodeless discharge lamps produced some variation. As a result, the highest value was used as the lower detection limit when the waste/soil column data were plotted.

Beryllium--

The AAS equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 234.9 nm
Slit Setting: 4 (0.7 nm)
Light Source: Perkin-Elmer hollow cathode lamp.
Burner Type: Nitrous oxide, single slot, 2-inch long slot.
Fuel: Acetylene, flow rate at 68 on burner control box.
Oxidant: Air, flow rate at 55 on burn control box.
Detection Limit: 0.02 microgram/milliliter.

Standards were made by diluting a stock standard solution containing 1000 micrograms beryllium/milliliter to the desired concentrations with distilled water containing one percent nitric acid and 1000 micrograms sodium/milliliter.

Cadmium--

The AAS equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 228.8 nm
Slit Setting: 4 (0.7 nm).
Light Source: Perkin-Elmer hollow cathode lamp.
Burner Type: Air-acetylene, single slot, 4-inch long slot.
Fuel: Acetylene, flow rate at 32 on burner control box.
Oxidant: Air, flow rate at 40 on burner control box.
Detection limit: 0.02 to 0.05 microgram/milliliter. The detection limit varied due to differences in sample composition.

Standards were made by diluting a commercially prepared stock standard solution containing 1000 micrograms cadmium/milliliter to the desired concentration with distilled water containing one percent nitric acid.

Chromium--

The equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 356.9 nm
Slit Setting: 4 (0.7 nm)
Light Source: Perkin-Elmer hollow cathode lamp.
Burner Type: Air-acetylene, single slot, 4-inch long slot.
Fuel: Acetylene, flow rate at 47 on burner control box.
Oxidant: Air, flow rate at 55 on burner control box.
Detection Limit: 0.05 microgram/milliliter.

Standards were made by diluting a commercially prepared stock standard solution containing 1000 micrograms chromium/milliliter to the desired concentration with distilled water containing one percent nitric acid.

Copper--

The AAS equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 324.7 nm
Slit Setting: 4 (0.7 nm).
Light Source: Perkin-Elmer hollow cathode lamp.
Burner Type: Air-acetylene, single slot, 4-inch long slot.
Fuel: Acetylene, flow rate at 35 on burner control box.
Oxidant: Air, flow rate at 55 on burner control box.
Detection Limit: 0.02 to 0.05 microgram/milliliter. The detection limit varied due to differences in sample composition.

Standards were made by diluting a commercially prepared stock solution containing 1000 micrograms copper/milliliter to the desired concentration with distilled water containing one percent nitric acid.

Lead--

The AAS equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 283.3 nm
Slit Setting: 4 (0.7 nm).
Light Source: Perkin-Elmer Electrodeless discharge lamp.
Burner Type: Air-acetylene, single shot, 4-inch long slot.
Fuel: Acetylene, flow rate at 40 on burner control box.
Oxidant: Air, flow rate at 55 on burner control box.
Detection Limit: 0.1 to 0.2 microgram/milliliter.

Standards were made by diluting a commercially prepared stock standard solution containing 1000 micrograms lead/milliliter to the desired concentrations with distilled water containing one percent nitric acid.

Mercury--

Equipment: Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer equipped with a Perkin-Elmer Model 56 strip chart recorder and a Perkin-Elmer Flameless Mercury Analysis System.

Wavelength: 253.7 nm.

Slit Setting: 4 (0.7 nm).

Light Source: Perkin-Elmer hollow cathode lamp.

Detection Limit: 0.02 microgram mercury in 100 ml.

A 1000 micrograms mercury/milliliter stock standard solution was made by dissolving 1.080 grams of mercury (II) oxide in a minimum amount of (1:1) hydrochloric acid and distilled water and diluted to one liter with distilled water. Standards were prepared by diluting this stock with distilled water containing one percent (volume:volume) hydrochloric acid.

Nickel--

Equipment: The AAS equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 232.0 nm

Slit Setting: 3 (0.2 nm).

Light Source: Perkin-Elmer hollow cathode lamp.

Burner Type: Air-Acetylene, single slot, 4-inch long slot.

Fuel: Acetylene, flow rate at 40 burner control box.

Oxidant: Air, flow rate at 55 on burner control box.

Detection Limit: 0.05 microgram/milliliter

Standards were made by diluting a commercially prepared stock standard solution containing 1000 micrograms nickel/milliliter to the desired concentration with distilled water containing one percent nitric acid.

Zinc--

The AAS equipment was used in the concentration mode using three second integration for calibration of the digital readout display.

Wavelength: 213.9 nm

Slit Setting: 4 (0.7 nm).

Light Source: Perkin-Elmer hollow cathode lamp

Burner Type: Air-acetylene, single slot, 4-inch long slot.

Fuel: Acetylene, flow rate at 45 on burner control box.

Oxidant: Air, flow rate at 55 on burner control box.

Detection Limit: 0.02 to 0.05 microgram/milliliter. The detection limit varied due to differences in sample composition.

Standards were made by diluting a commercially prepared stock standard solution containing 1000 micrograms zinc/milliliter to the desired concentrations with distilled water containing one percent nitric acid.

Validation of Atomic Absorption Analysis

Reference samples were received from the EPA Project Officer. One set of reference samples contained trace quantities of cadmium, chromium, copper, lead, zinc, arsenic, and selenium. The reference samples were prepared for analysis as directed. Samples were first analyzed directly without using extraction procedures. The results are shown in Table 29.

TABLE 29

ATOMIC ABSORPTION ANALYSIS OF EPA REFERENCE SAMPLES

Metal	Sample 1		Sample 2		Sample 3	
	$\mu\text{g/l}$ found	$\mu\text{g/l}$ actual	$\mu\text{g/l}$ found	$\mu\text{g/l}$ actual	$\mu\text{g/l}$ found	$\mu\text{g/l}$ actual
Cadmium	<10	1.8	10	16	65	73
Chromium	<50	9.2	80	83	410	406
Copper	<20	9.0	50	67	320	314
Lead	<50	28.0	80	92	370	350
Zinc	10.0	10.0	60	79	340	367

Except for zinc, the concentrations of the metals in Sample 1 were below the detection limit for direct analysis. They are also below maximum permissible contamination levels in drinking water.¹³ The concentration of the metals in Sample 2 are at the low end of the range of interest and just above the maximum permissible contamination levels. However, reliable direct analysis can be made.

In order to further validate our techniques, Samples 1 and 2 were extracted with methyl iso-butyl ketone and the extracts analyzed for cadmium and copper. The results are shown in Table 30.

TABLE 30

ATOMIC ABSORPTION ANALYSIS OF EXTRACTS FROM EPA REFERENCE SAMPLES

Metal	Sample 1		Sample 2	
	$\mu\text{g/l}$ found	$\mu\text{g/l}$ actual	$\mu\text{g/l}$ found	$\mu\text{g/l}$ actual
Cadmium	1.5	1.8	15.0	16.0
Copper	9.0	9.0	66.0	67.0

The results show that excellent results can be obtained at these very low levels provided suitable extraction procedures are used. However, extraction significantly increases the time necessary to perform the analysis. Because of the large number of samples generated daily by the soil and waste columns this would constitute a large increase in the overall analysis effort.

The Project Officer also furnished three samples containing mercury. Two methods were used to determine mercury content. These methods were oxidation by potassium permanganate or potassium persulfate. The results are shown in Table 5.

TABLE 31

ATOMIC ABSORPTION ANALYSIS OF EPA REFERENCE SAMPLES CONTAINING MERCURY

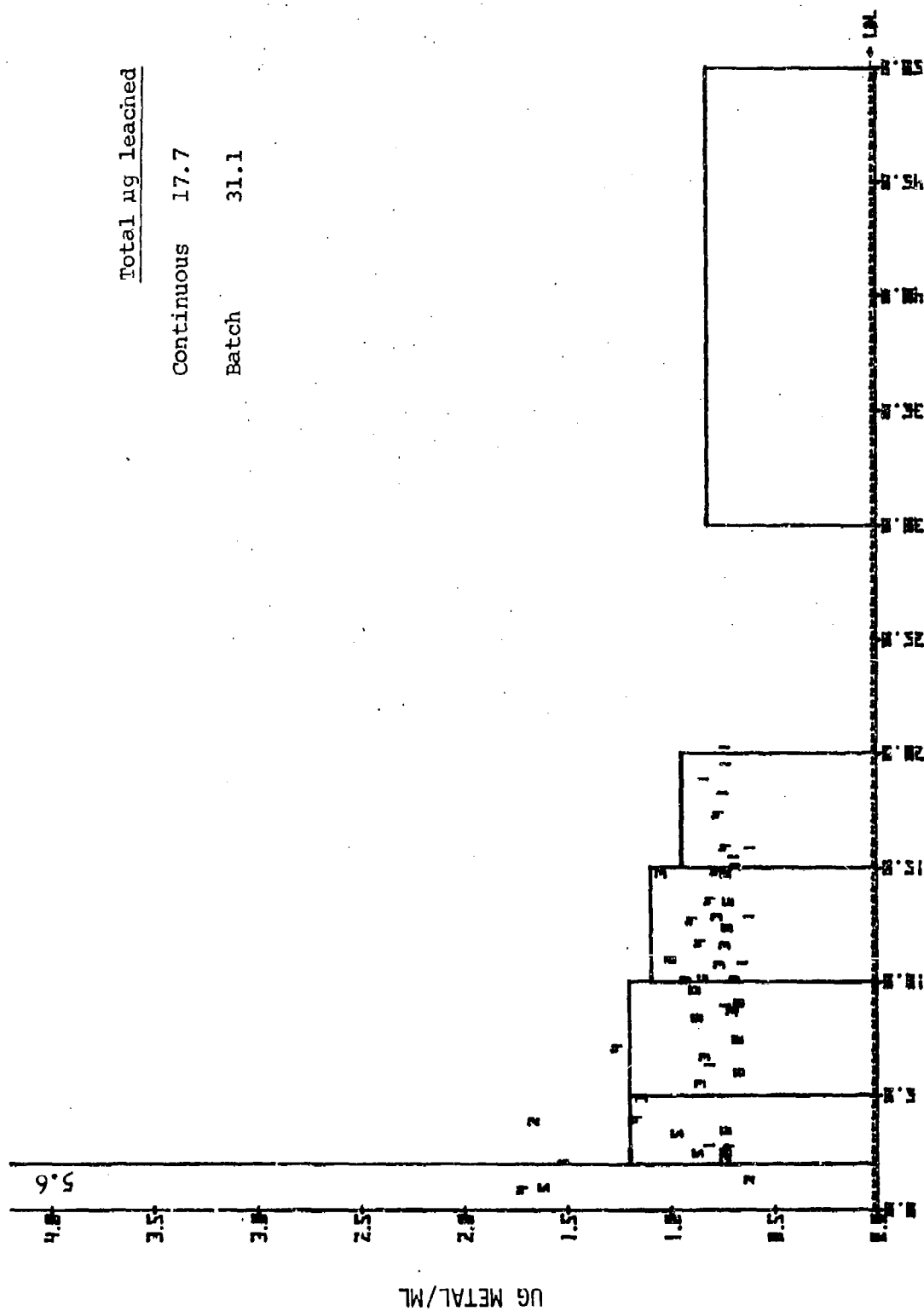
Sample Number	Recovery of Mercury (ug/l)		
	Found		Actual
	Permanganate	Persulfate	
1	0.23	0.95	0.42
2	2.0	2.8	2.4
3	5.2	7.5	7.0

The results show that the potassium persulfate method must be used to measure the mercury content of a sample if organo mercury compounds are present. The results obtained were somewhat higher than the values reported by EPA. This may indicate that low level laboratory contamination was introduced while preparing the EPA reference samples for analysis.

Total ug leached

Continuous 17.7

Batch 31.1



CLM VOLUME (ML/CM)

FIGURE 65: CADMIUM LEACHED FROM ELECTROPLATING WASTE BY WATER

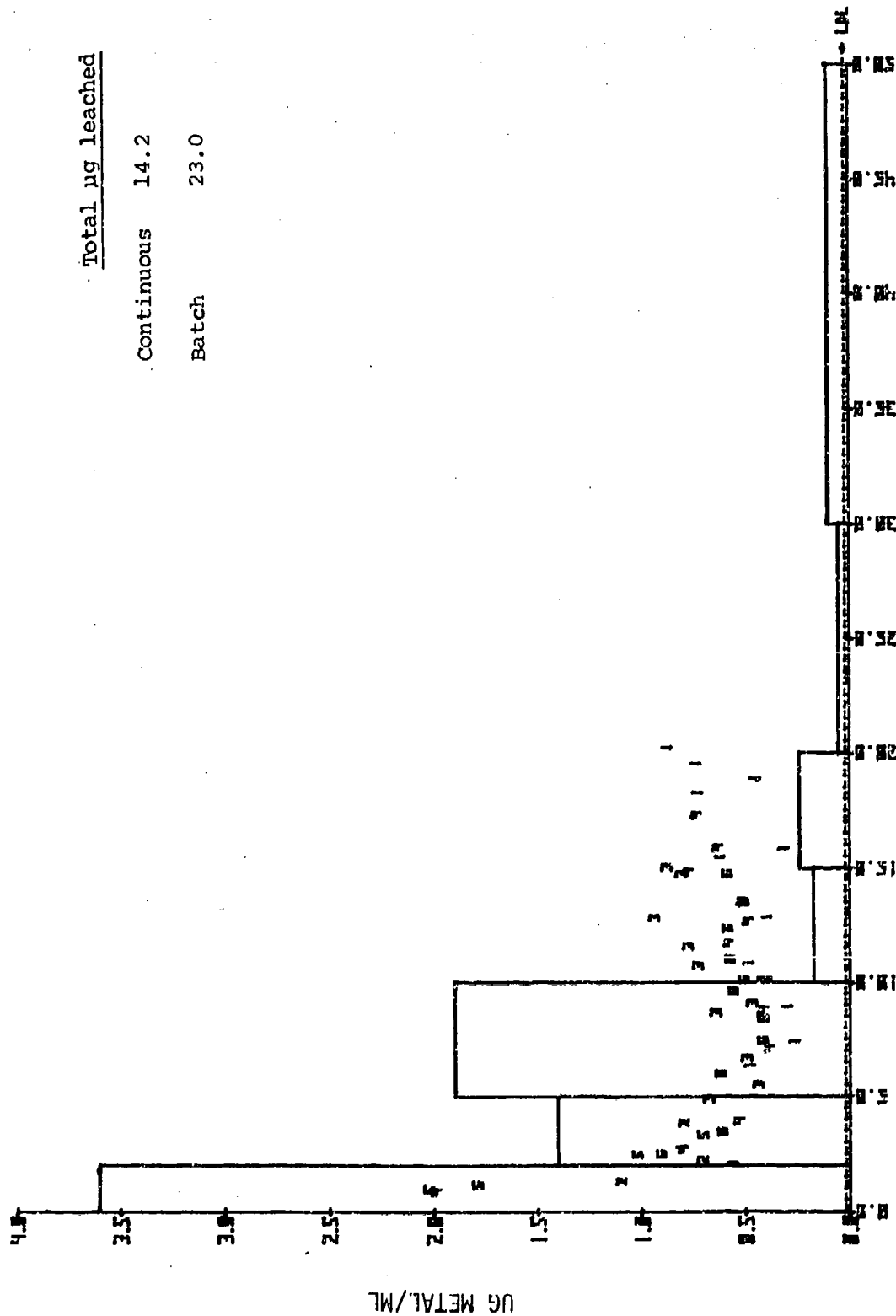
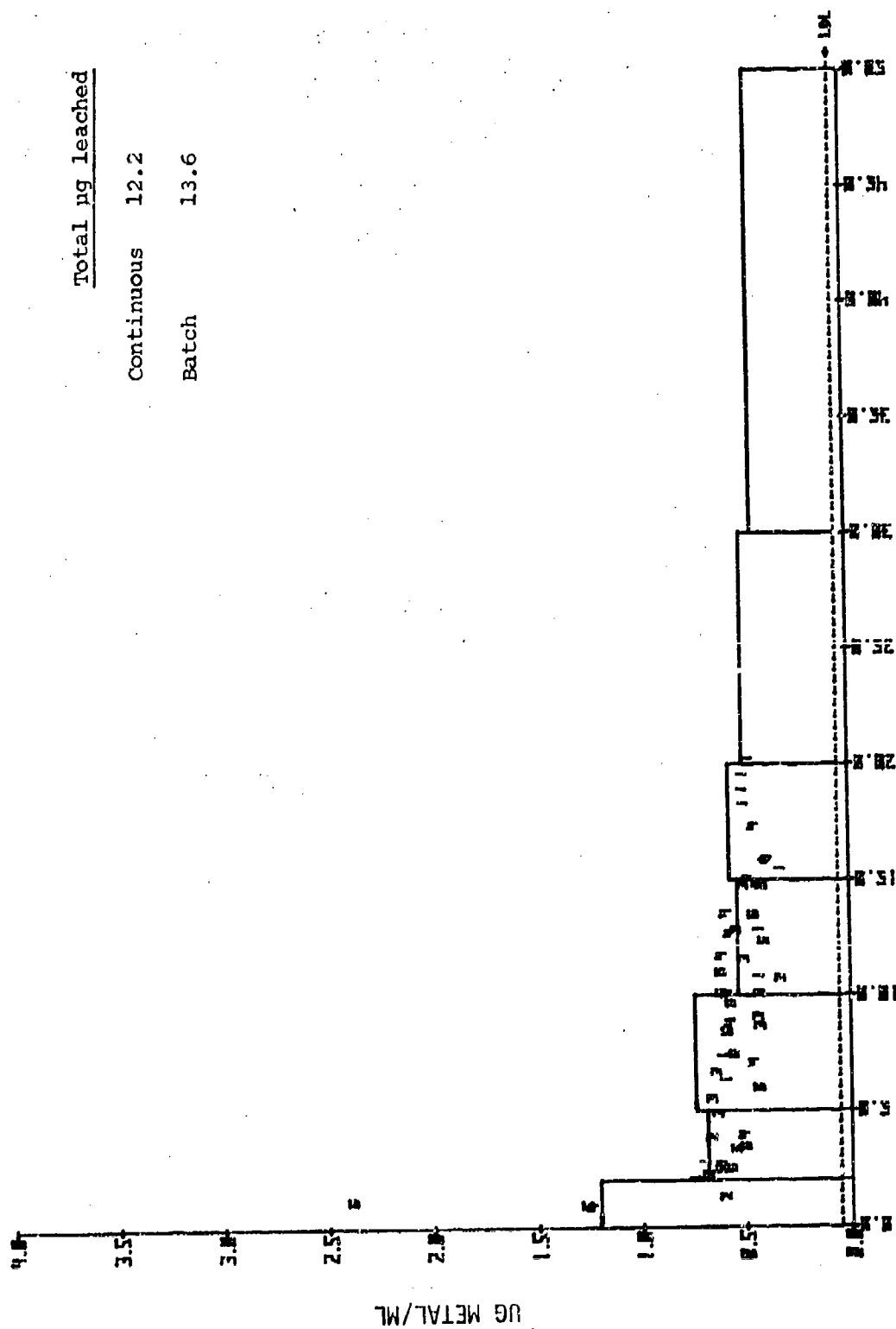


FIGURE 66: COPPER LEACHED FROM ELECTROPLATING WASTE BY WATER

Total ug leached

Continuous 12.2

Batch 13.6



CUM VOLUME (ML/GH)

FIGURE 67: NICKEL LEACHED FROM ELECTROPLATING WASTE BY WATER

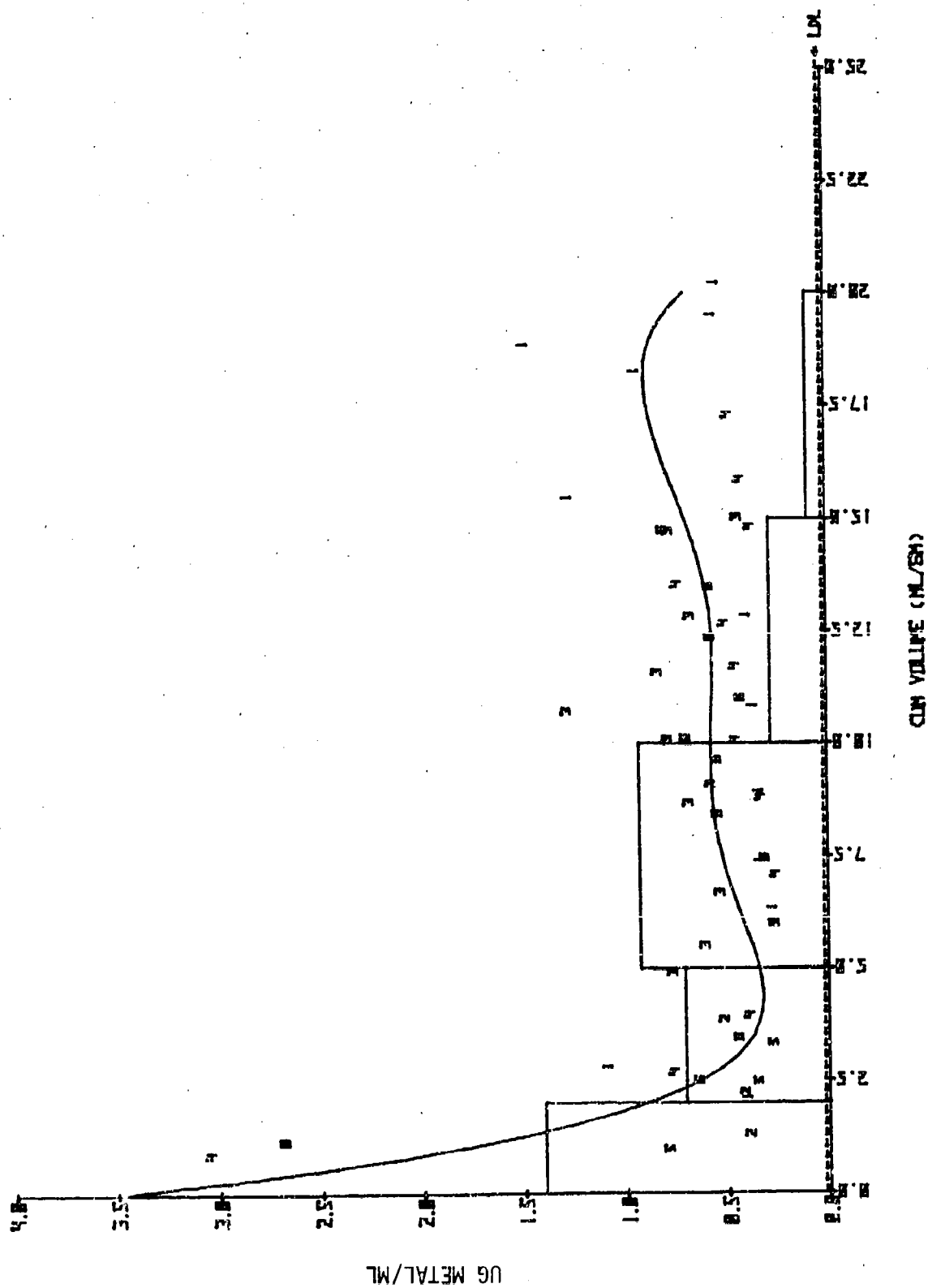


FIGURE 68: ZINC LEACHED FROM ELECTROPLATING WASTE BY WATER

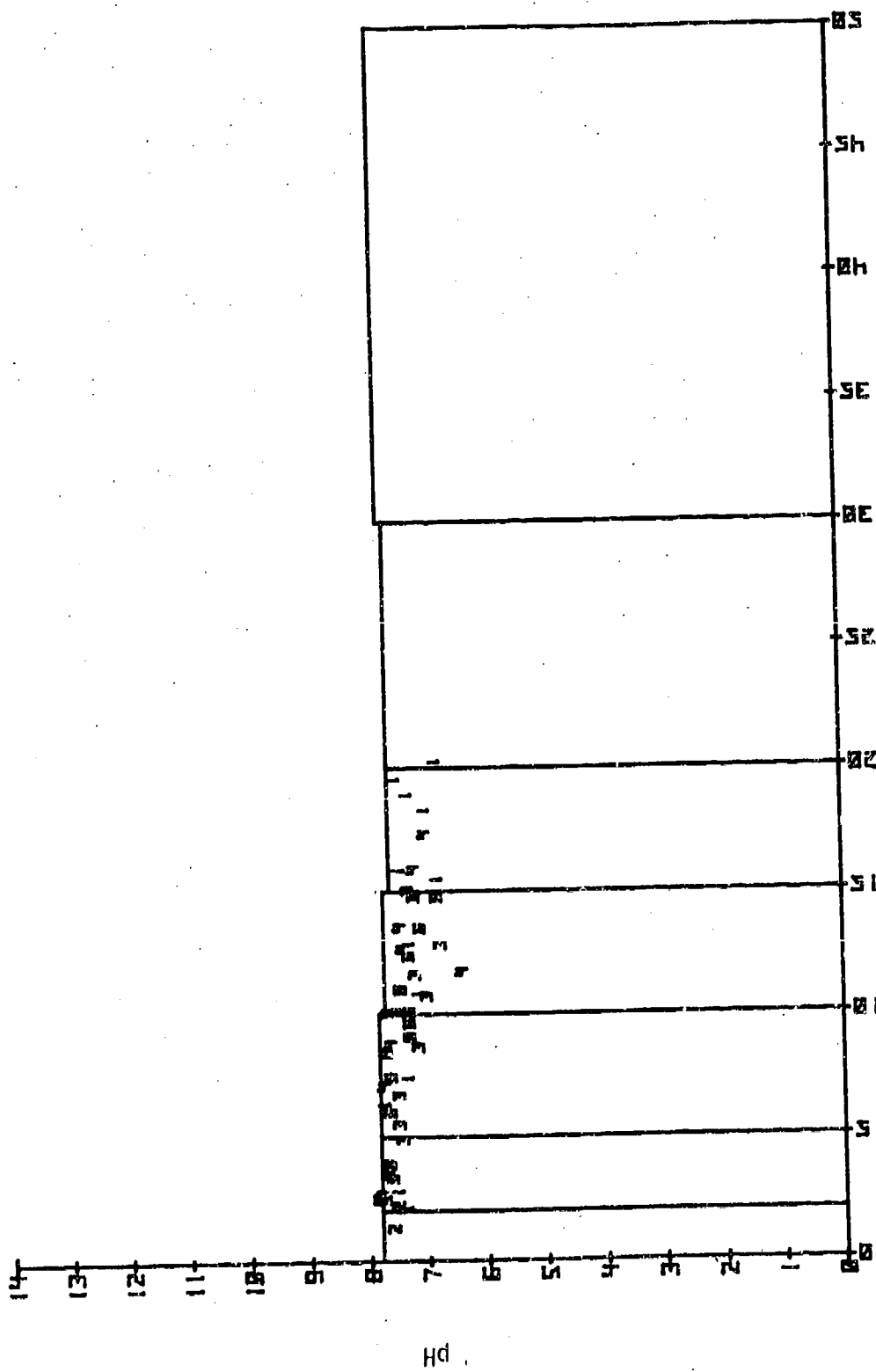


FIGURE 59: pH OF SOLUTION LEACHED FROM ELECTROPLATING WASTE BY WATER

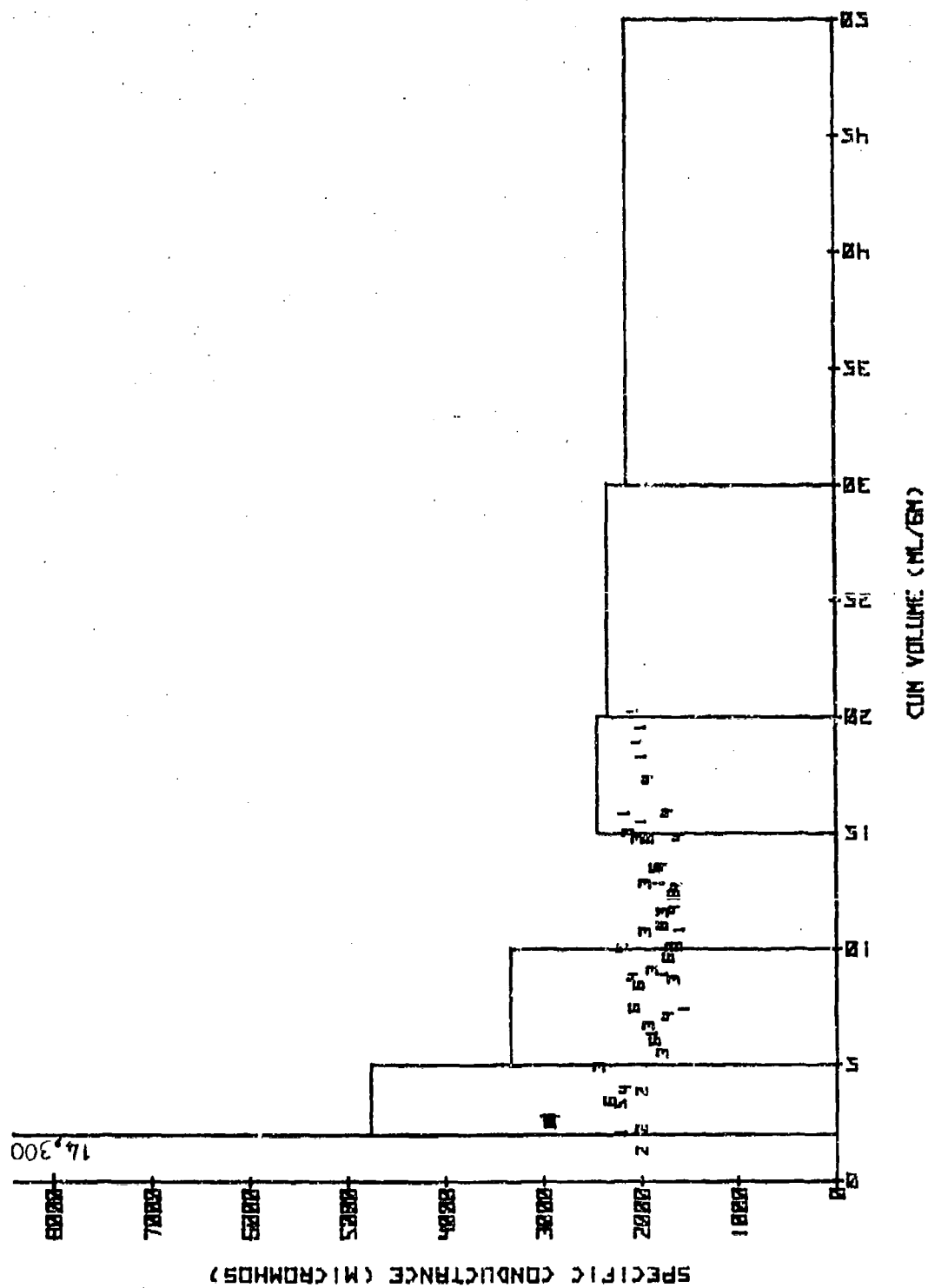


FIGURE 70: CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING WASTE BY WATER

SECTION 5

CONTAMINANT MOVEMENT IN SOIL

INTRODUCTION

The five soils used in this study were Kalkaska soil from Michigan, Davidson soil from North Carolina, Anthony soil from Arizona, Chalmers soil from Indiana, and Nicholson soil from Kentucky. These soils were collected from the B-horizon zone (30 - 100 centimeters in depth) at each location. The same soils have been used in studies conducted at other laboratories and have been classified both chemically and physically (15-18).

Small samples of each of the soils were mixed with aliquots of the waste extracts obtained from the batch serial extraction experiments. The samples were mixed for 24 hours, filtered and the metals remaining in the filtrate measured by AAS. From these experiments, we were able to select the soil which removed each of the metals to the largest extent and the soil which removed them the least. These two soils were then used to prepare soil columns and were used in all subsequent soil column metal migration studies. The following is a brief description of each of the soils.

DESCRIPTION OF THE SOILS

Kalkaska Soil

Kalkaska soil is a yellowish brown sand which is classified as a Spodosol. The sample was collected in Osceola County, Michigan, by personnel from the Department of Soil Science, Michigan State University. The soil is strongly acid and contains very little clay and silt (over 90 percent of the soil is sand). The clay mineral composition (the less than 2 micron soil separates) shows a moderate amount of chlorite and a small amount of kaolinite present. Water penetrates Kalkaska soil columns very rapidly.

Chalmers Soil

Chalmers Soil is gray, silty, clay loam classified as a Mollisol. The sample was collected by personnel from the Soil Conservation Service, U.S. Department of Agriculture, Greencastle, Indiana. It is slightly acid to neutral in pH and contains large percentages of clay and silt (over

90 percent). The clay mineral composition (the less than 2 micron separates) shows a predominance of kaolinite. Water penetrates Chalmers soil columns slowly.

Davidson Soil

Davidson soil is a dark red clay classified as a Ultisol. The sample was collected in Rowan County, North Carolina by personnel from the Department of Soil Science, North Carolina State University, Raleigh, North Carolina. The soil is slightly acid and contains over 60 percent clay. The remainder is evenly divided between silt and sand. The clay mineral composition (the less than 2 micron soil separates) shows a predominance of kaolinite. Water penetrates columns of Davidson soil moderately rapidly.

Nicholson Soil

Nicholson soil is a yellowish brown silty clay classified as an Alfisol. The sample was collected in Kentucky by the EPA Project Officer, Cincinnati, Ohio. The soil is slightly acid to neutral and contains nearly equal quantities of clay and silt (combined, the clay and silt fractions constitute 95 percent of the soil texture). The clay mineral composition (the less than 2 micron soil separates) shows a predominance of vermiculite. Water penetrates columns of Nicholson soil slowly.

Anthony Soil

Anthony soil is a dark brown sandy loam classified as an Entisol. The sample was collected by personnel from the Arizona Agricultural Experiment Station, the University of Arizona, Tucson, Arizona. The soil is slightly alkaline and contains over 70 percent sand. The remainder is nearly equal quantities of silt and clay. The clay material composition (the less than 2 micron soil separates) shows a heavy amount of montmorillonite, a moderate amount of mica and a small amount of kaolinite. Water penetrates Anthony soil columns rapidly.

Some of the other characteristics of these five soils are summarized in Table 29.

BATCH ATTENUATION STUDIES

Procedures

Preliminary batch soil attenuation studies were conducted both to identify a pair of soils having quite different attenuation capacities and to provide some insight into soil-leachate interactions as basis for designing the soil column studies to be conducted later.

These studies were accomplished by mixing small quantities of each soil with water and landfill leachate extracts of each waste for 24 hours using two ratios of soil to extract, 2 grams soil/20 milliliters extract and 10 grams soil/20 milliliters extract. The high ratio waste:solvent

extracts (1:2) were used as described in Section 4 under batch solubilization studies. Control samples were prepared by mixing soil with water and land-fill leachate.

TABLE 32. PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS USED IN THIS STUDY

Soil	Soil Paste ph	Cation Exchange Capacity	Surface Area	Free Iron Oxides	Texture		
					Sand	Silt	Clay
		meq/100g	m ² /g	%	%	%	%
Kalkaska	4.7	10	8.9	1.8	91	4	5
Davidson	6.2	9	51.3	17.0	19	20	61
Chalmers	6.6	26	125.6	3.1	7	58	35
Nicholson	6.7	37	120.5	5.6	3	47	49
Anthony	7.8	6	19.8	1.8	71	14	15

After the initial extractions, the wastes were recovered and mixed with fresh portions of solvent for 72 hours. The mixtures of waste and solvent were filtered and the filtrates were mixed with fresh portions of each soil. These mixtures of soil and of waste extract were filtered after 24 hours, and the filtrates analyzed for the metals of interest. Two extracts of the same portion of waste were used in these studies because the composition of the waste extract (pH, ionic strength, metals, major metallic cations such as sodium, potassium, calcium, magnesium) changes significantly from one extract to the next and it was expected that these changes would affect the capacity of the soils to remove metals from the waste extracts.

Results and Discussion

General--

By summing the percent removed by the soils of one or more metals in one or more extracts, a number of rankings of soils, according to their removal capacities, was developed. Although relative positions of the soils in the ranking varied, depending on which metals and extracts were examined, Kalkaska and Anthony were consistently poor attenuators and Chalmers and Davidson were consistently very good attenuators.

An increase in the ratio of soil to extract generally resulted in an increased metal removal but the increase in removal was less than proportional to the increase in the soil:extract ratio. This is likely due to

the high concentrations of other, non-hazardous, ions present in the waste extracts. These ions (e.g., calcium, magnesium and sodium) compete with the metals for sorption sites on the soil and drastically reduce the amount of metal that can be removed from solution by a given amount of soil. This same effect has been previously reported in studies of metal removal from single and multiple salt aqueous solutions and municipal land fill leachate (19). It was also noted in the same study that the ions naturally present on the soil may be displaced and compete with the metals of interest for sorption sites. Increasing the ratio of soil to extract would increase the concentration of these displaced ions and thus further decrease the amount of metal removed per gram of soil.

Electroplating Waste Batch Studies--

Water Extract--The percent removal of metals from the water extract of the electroplating waste by each of the soils is shown in Table 30. The composition of the waste extracts are shown in Table 8.

The Kalkaska soil removed the least amount of metals from solution and the Davidson soil removed the most. The ranking of the soils placed with electroplating waste leachate according to increasing attenuation capacity is as follows; Kalkaska (49), Nicholson (53), Anthony (75), Chalmers (87), Davidson (88). The numbers in parentheses are the average percent removal of metals for all metals, extracts and soil weights.

It was expected that percent removal of metals from the second and third extracts would increase as the amount of other cations in solution and competition for binding sites on the soil decreased. This was not found to be the case. Even though the amount of materials such as calcium and potassium extracted from the waste were reduced, the quantity was still great and, at the same time, the amount of metals in solution was also decreasing. It must be remembered that the concentration of many of the metals remaining in the filtrate from the batch studies was near the detection limit, making it difficult to show differences between extracts and soil weights.

Landfill Leachate Extract--The percent removal of metals from the landfill leachate extract of the electroplating waste by each of the soils is shown in Table 31. The composition of the waste extracts are shown in Table 10. The Anthony soil removed the least and Davidson soil removed the most metals. The ranking of the soils is as follows; Anthony (45), Kalkaska (52), Nicholson (58), Chalmers (64), Davidson (73),

The average percent removals of metals was generally lower than for the water extract. This is likely due to the higher concentration of metals initially in solution (compare Tables 8 and 10) and to competition for binding sites by the organic and inorganic solutes in the leachate.

The low relative ranking of Kalkaska and Anthony soils both in the studies with water and landfill leachate were expected because of course

TABLE 33. SOIL ATTENUATION OF METALS EXTRACTED FROM ELECTROPLATING WASTE
USING DISTILLED WATER

SOIL TYPE	Percent Removal of Metals by Soils				
	Cd	Cr	Cu	Ni	Zn
1. KALKASKA SOIL					
a. <u>1st Extract</u>					
2 grams soil	24	100	76	19	7
10 grams soil	27	100	91	28	0
b. <u>2nd Extract</u>					
2 grams soil	31	*	88	31	14
10 grams soil	33	*	94	39	12
c. <u>3rd Extract</u>					
2 grams soil	32	100	70	21	0
10 grams soil	48	100	65	100	0
2. CHALMERS SOIL					
a. <u>1st Extract</u>					
2 grams soil	85	100	97	56	90
10 grams soil	100	100	97	67	68
b. <u>2nd Extract</u>					
2 grams	88	*	100	63	98
10 grams soil	100	*	100	75	98
c. <u>3rd Extract</u>					
2 grams soil	100	100	100	63	98
10 grams soil	100	100	60	54	**

(Continued)

*The concentration of chromium in the 2nd extract was below the detection limit of the analytical method.

**Not determined

TABLE 33. (Continued)

SOIL TYPE	Percent Removal of Metals By Soils				
	Cd	Cr	Cu	Ni	Zn
3. ANTHONY SOIL					
a. <u>1st Extract</u>					
2 grams soil	68	100	64	47	78
10 grams soil	87	100	91	66	73
b. <u>2nd Extract</u>					
2 grams soil	75	*	90	56	91
10 grams soil	92	*	100	72	86
c. <u>3rd Extract</u>					
2 grams soil	96	14	100	55	84
10 grams soil	85	29	75	63	86
4. <u>DAVIDSON SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	88	100	87	61	93
10 grams soil	92	100	95	74	88
b. <u>2nd Extract</u>					
2 grams soil	100	*	100	75	91
10 grams soil	100	*	100	75	100
c. <u>3rd Extract</u>					
2 grams soil	100	100	100	66	93
10 grams soil	98	100	100	70	87

(Continued)

TABLE 33. (Continued)

SOIL TYPES	Percent Removal of Metals By Soils				
	Cd	Cr	Cu	Ni	Zn
5. <u>NICHOLSON SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	22	100	87	16	0
10 grams soil	62	100	100	46	0
b. <u>2nd Extract</u>					
2 grams soil	38	*	80	31	5
10 grams soil	56	*	100	57	0
c. <u>3rd Extract</u>					
2 grams soil	12	100	*	29	0
10 grams soil	84	100	100	44	0

TABLE 34. SOIL ATTENUATION OF METALS EXTRACTED FROM ELECTROPLATING WASTE
USING LANDFILL LEACHATE

SOIL TYPE	Percent Removal of Metals By Soils				
	Cd	Cr	Cu	Ni	Zn
1. <u>KALKASKA SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	24	100	54	42	74
10 grams soil	44	100	80	60	83
b. <u>2nd Extract</u>					
2 grams soil	17	32	42	11	25
10 grams soil	37	52	70	41	61
2. <u>CHAMBERS SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	39	100	57	49	92
10 grams soil	67	100	88	79	95
b. <u>2nd Extract</u>					
2 grams soil	22	57	49	20	40
10 grams soil	47	72	76	52	70
3. <u>ANTHONY SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	18	100	30	29	90
10 grams soil	36	100	54	55	95
b. <u>2nd Extract</u>					
2 grams soil	16	27	26	11	22
10 grams soil	26	52	47	26	53

(Continued)

TABLE 34. (Continued)

SOIL TYPE	Percent Removal of Metals By Soils				
	Cd	Cr	Cu	Ni	Zn
4. <u>DAVIDSON SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	54	100	68	76	96
10 grams soil	77	100	92	92	98
b. <u>2nd Extract</u>					
2 grams soil	26	66	57	32	60
10 grams soil	51	92	84	63	80
5. <u>NICHOLSON SOIL</u>					
a. <u>1st Extract</u>					
2 grams soil	35	100	57	54	95
10 grams soil	39	100	83	52	84
b. <u>2nd Extract</u>					
2 grams soil	19	66	51	11	22
10 grams soil	38	72	73	41	62

texture and low cation-exchange capacity and surface area. Likewise, the high ranking for the Davidson soil was expected because of its high percentage of free iron oxide, a material closely associated with retention of heavy metals and some anions.

The low percent metal removal by Nicholson, a soil having a high clay content exchange capacity, and surface area was unexpected. The reason for low removal by the Nicholson in the electroplating waste study (contrasted with much higher removals in the other waste studies) is not known at this time.

Nickel-Cadmium Battery Waste Batch Studies--

Only distilled water extracts were obtained from this waste sample. The large sample extracted with landfill leachate was lost when the glass container shattered during the first extraction. The percent removal of metals from the water extract of the nickel-cadmium battery production waste by each of the soils is shown in Table 32. The composition of the waste extract is shown in Table 15.

Removal of nickel from the first extract was quite low compared to removals from the second and third extracts. Since the electrical conductivity of the second extract (8,960 micromhos) was much less than that of the first extract (34,500 micromhos) it appears that competition from other solutes was responsible for the low percent removal from the first extract by all soils.

The average percent removal of the metals and the ranking of the soils according to attenuation capacity is as follows: Kalkaska (56), Anthony (81), Chalmers (81), Nicholson (83), Davidson (85).

Two unusual results, the close grouping of four of the soils and the color of leachates, were noted in this study. All the soils except Kalkaska, showed essentially the same total removal of metals with slight variations in the distribution of removal percentages between extracts and soil weights. The strong alkalinity of the waste extract (pH 11-12) and the fact that Kalkaska was the only soil having such a low pH (4-7) suggests that pH-controlled precipitation was a major removal mechanism for metals from this waste.

The filtrates from the batch soil experiments with Kalkaska and Davidson were dark brown and light yellow respectively. Filtrates from these soils in studies with other wastes were nearly colorless. The colors were likely due to a reaction between soil organic matter and the alkalinity of the Ni-Cd battery waste extract. Further work was not conducted on this aspect of the interaction between the soil and the waste extract. Since the colors in the soil filtrates are likely due to dissolve or dispersed organic matter, there is a possibility that organic contamination would be a problem from disposal of this waste on certain soils.

TABLE 35. SOIL ATTENUATION OF HEAVY METALS EXTRACTED FROM NICKEL-CADMIUM BATTERY WASTE USING DISTILLED WATER

SOIL TYPE	Percent Removal of Metals by Soil	
	Ni	Cd
1. <u>KALKASKA SOIL</u>		
a. <u>1st Extract</u>		
2 grams soil	9	22
10 grams soil	0	0
b. <u>2nd Extract</u>		
2 grams soil	95	70
10 grams soil	92	73
c. <u>3rd Extract</u>		
2 grams soil	100	35
10 grams soil	100	73
2. <u>CHALMERS SOIL</u>		
a. <u>1st Extract</u>		
2 grams soil	12	96
10 grams soil	6	100
b. <u>2nd Extract</u>		
2 grams soil	96	100
10 grams soil	100	100
c. <u>3rd Extract</u>		
2 grams soil	100	100
10 grams soil	100	100
3. <u>ANTHONY SOIL</u>		
a. <u>1st Extract</u>		
2 grams soil	21	80
10 grams soil	9	74

(Continued)

TABLE 35. (Continued)

SOIL TYPE	Percent Removal of Metals By Soil	
	Ni	Cd
b. <u>2nd Extract</u>		
2 grams soil	95	98
10 grams soil	95	100
c. <u>3rd Extract</u>		
2 grams soil	100	100
10 grams soil	100	100
4. <u>DAVIDSON SOIL</u>		
a. <u>1st Extract</u>		
2 grams soil	15	88
10 grams soil	29	88
b. <u>2nd Extract</u>		
2 grams soil	97	100
10 grams soil	100	100
c. <u>3rd Extract</u>		
2 grams soil	100	100
10 grams soil	100	100
5. <u>NICHOLSON SOIL</u>		
a. <u>1st Extract</u>		
2 grams soil	6	78
10 grams soil	34	86
b. <u>2nd Extract</u>		
2 grams soil	96	100
10 grams soil	100	100
c. <u>3rd Extract</u>		
2 grams soil	100	100
10 grams soil	100	100

A second sample of Ni-Cd battery waste was collected because there was not sufficient material in the first sample for all the work. A second, abbreviated, batch study was conducted with the second sample. Only the first waste extract and ten grams of soil were used. The concentrations of nickel and cadmium found in the waste extracts are shown in Table 16 and the percent removal of these metals by the soils are shown in Table 33 along with the comparable figures from the study with first waste sample. The average percent removal and rankings for the soils in the batch study with the second waste is as follows: Kalkaska (7), Nicholson (7), Chalmers (54), Anthony (68), Davidson (75).

For comparison with the second waste, the data from the first waste study for ten grams of soil and the first extract have been used to calculate average percent removal and soil ranking and is as follows: Kalkaska (0), Anthony (42), Chalmers (53), Davidson (59), Nicholson (60).

Note how this ranking differs from the comparable ranking for the second waste and from the ranking for the first waste based on data from three extractions and both weights of soil.

The reasons for the differences in metal removal from extracts of the two wastes are not known. There are striking differences in the waste leaching behavior. Note that the second extract of the first waste (Table 15) had a slightly lower pH and a much lower specific conductance; the second extract of the second waste (Table 16) had a much lower pH and a significantly higher specific conductance. However, the first extracts of both waste are very similar in pH, specific conductance and concentration of nickel and cadmium so the differences in leaching behavior in the later extracts do not help to explain the differences in metal removal.

The differences in leaching behavior of waste samples from the same location and the differences in metal removal from extracts with similar chemical characteristics emphasize the need for detailed studies to define waste characteristics and disposal procedures at even a single location.

Inorganic Pigment Waste Batch Studies--

Water Extract--The concentrations of metals in the water extract of the pigment waste are shown in Table 20 and the percentages removed by the various soils are shown in Table 34. The average percent removal of metals and ranking of the soils is as follows: Anthony (48), Kalkaska (58), Nicholson (60), Chalmers (56), Davidson (80).

The increase in removal from this waste extract was more closely correlated with increases in weight of soil than for any other waste.

Landfill Leachate Extract--The landfill leachate extract of the inorganic pigment waste contained higher concentrations of all metals (except chromium) than did the water extract (Table 20). The removal of these metals by the various soils is shown in Table 35. The average

TABLE 36. SOIL ATTENUATION OF HEAVY METALS EXTRACTED FROM NICKEL-CADMIUM BATTERY WASTE USING DISTILLED WATER

Soil Type 10 grams	Percent Removal of Metals by Soil	
	Ni	Cd
1. Kalkaska		
Waste No. 1*	0	0
Waste No. 2**	13	0
2. Chalmers		
Waste No. 1	6	100
Waste No. 2	39	69
3. Anthony		
Waste No. 1	9	74
Waste No. 2	40	95
4. Davidson		
Waste No. 1	29	88
Waste No. 2	69	82
5. Nicholson		
Waste No. 1	34	86
Waste No. 2	13	0

* Original waste material; figures taken from Table 32.

** New waste material

removal percentages for each soil and ranking is as follows: Nicholson (58), Kalkaska (63), Chalmers (73), Anthony (75), Davidson (80). The total amounts removed were generally higher for the landfill leachate extract than for the water extract. As with the water extract, the increased removal by 10 grams of soil (as compared to removal by 2 grams of soil) was more nearly proportional to the increase in weight of soil than was the case for any other waste.

Water Base Paint Waste Batch Studies--

Water Extracts--The concentrations of metals in the water extract of the paint waste are shown in Table 24 and the percent removal of metals by each soil are shown in Table 36. The average percent removal and ranking of the soils are as follows: Anthony (65), Nicholson (72), Kalkaska (79), Chalmers (80), Davidson (87).

Because the metals in the second extract were mostly below detection limits, only data from batch studies with the first extract were available to develop the ranking of soils and average percent removals.

TABLE 37. SOIL ATTENUATION OF METALS EXTRACTED FROM INORGANIC PIGMENT WASTE USING DISTILLED WATER

SOIL TYPE	Percent Removal of Metals by Soil						
	Cd	Cr	Cu	Ni	Zn	Hg	Pb
1. KALKASKA SOIL							
a. 1st Extract							
2 grams soil	50	41	73	10	*	100	48
10 grams soil	62	92	87	14	*	100	56
b. 2nd Extract							
2 grams soil	0	20	**	0	*	100	100
10 grams soil	50	66	**	0	*	100	100
2. CHALMERS SOIL							
a. 1st Extract							
2 grams soil	50	3	100	4	*	100	44
10 grams soil	75	59	100	90	*	100	60
b. 2nd Extract							
2 grams soil	100	9	**	0	**	100	100
10 grams soil	100	49	**	0	**	100	100
3. ANTHONY SOIL							
a. 1st Extract							
2 grams soil	50	3	73	6	*	100	40
10 grams soil	75	0	100	10	*	100	52
b. 2nd Extract							
2 grams soil	0	3	**	0	**	100	100
10 grams soil	50	3	**	0	**	100	100
4. DAVIDSON SOIL							
a. 1st Extract							
2 grams soil	75	47	87	14	100	100	68
10 grams soil	100	86	100	40	100	100	100
b. 2nd Extract							
2 grams soil	100	9	**	0	**	100	100
10 grams soil	100	49	**	0	**	100	100
5. NICHOLSON SOIL							
a. 1st Extract							
2 grams soil	50	35	53	4	0	100	64
10 grams soil	25	71	100	30	0	100	100
b. 2nd Extract							
2 grams soil	0	26	**	0	**	100	100
10 grams soil	100	72	**	0	**	100	100

*No zinc was found in the extract. However, zinc was released from the soil by the waste extract. Thus more zinc was found in the soil extract than was initially present.

**No copper or zinc was found in the waste extract or the soil extract samples.

TABLE 38. SOIL ATTENUATION OF METALS EXTRACTED FROM INORGANIC PIGMENT WASTE USING LANDFILL LEACHATE

SOIL TYPE	Percent Removal of Metals by Soil						
	Cd	Cr	Cu	Ni	Zn ^a	Hg	Pb
1. KALKASKA SOIL							
a. 1st Extract							
2 grams soil	95	93	41	67	0	100	86
10 grams soil	100	100	83	84	0	100	95
b. 2nd Extract							
2 grams soil	27	90	29	92	0	50	74
10 grams soil	30	100	69	89	0	0	66
2. CHALMERS SOIL							
a. 1st Extract							
2 grams soil	86	88	47	100	0	100	81
10 grams soil	100	100	65	100	0	100	98
b. 2nd Extract							
2 grams soil	27	100	46	100	0	86	51
10 grams soil	79	100	89	100	0	99	100
3. ANTHONY SOIL							
a. 1st Extract							
2 grams soil	100	91	27	94	25	0	81
10 grams soil	100	100	66	100	100	100	96
b. 2nd Extract							
2 grams soil	18	96	17	98	0	95	62
10 grams soil	100	100	51	100	100	99	77
4. DAVIDSON SOIL							
a. 1st Extract							
2 grams soil	100	100	76	100	13	100	100
10 grams soil	100	100	94	100	0	100	100
b. 2nd Extract							
2 grams soil	76	100	46	99	0	98	62
10 grams soil	100	100	95	100	0	99	77
5. NICHOLSON SOIL							
a. 1st Extract							
2 grams soil	83	54	49	100	0	0	100
10 grams soil	76	85	66	95	0	100	100
b. 2nd Extract							
2 grams soil	24	87	40	100	0	89	4
10 grams soil	9	100	82	98	0	53	36

^aAlthough the leachate contained approximately 60 micrograms/milliliter zinc before being placed with the waste, the extract from the waste showed very little zinc from the landfill leachate. The soil extract generally contained more zinc than did the waste extract.

TABLE 33. SOIL ATTENUATION OF METALS EXTRACTED FROM WATER BASE PAINT WASTE USING DISTILLED WATER

SOIL TYPE	Percent Removal of Metals by Soil						
	Cd	Cr	Cu	Ni	Zn	Hg	Pb
1. KALKASKA SOIL							
a. 1st Extract							
2 grams soil	*	82	85	27	92	100	*
10 grams soil	*	91	88	45	77	100	
b. 2nd Extract							
2 grams soil	*	*	*	*	*	100	*
10 grams soil	*	*	*	*	*	100	*
2. CHALMERS SOIL							
a. 1st Extract							
2 grams soil	*	45	100	18	100	100	*
10 grams soil	*	91	100	45	100	100	*
b. 2nd Extract							
2 grams soil	*	*	*	*	*	100	*
10 grams soil	*	*	*	*	*	100	*
3. ANTHONY SOIL							
a. 1st Extract							
2 grams soil	*	27	85	36	77	100	*
10 grams soil	*	32	100	27	62	100	*
b. 2nd Extract							
2 grams soil	*	*	*	*	*	*	*
10 grams soil	*	*	*	*	*	*	*
4. DAVIDSON SOIL							
a. 1st Extract							
2 grams soil	*	68	92	45	69	100	*
10 grams soil	*	91	100	100	100	100	*
b. 2nd Extract							
2 grams soil	*	*	*	*	*	100	*
10 grams soil	*	*	*	*	*	100	*
5. NICHOLSON SOIL							
a. 1st Extract							
2 grams soil	*	73	88	27	85	100	*
10 grams soil	*	100	100	45	0	100	*
b. 2nd Extract							
2 grams soil	*	*	*	*	*	100	*
10 grams soil	*	*	*	*	*	100	*

*Concentration of these elements were below detection limits in the waste extract.

Landfill Leachate Extract--Concentrations of metals in the landfill leachate extract of the paint waste are shown in Table 24 and the percent removals of metals for each soil and extract are shown in Table 37. The average percent removal and ranking of soils, based on data from both extracts was: Anthony (68), Chalmers (68), Kalkaska (72), Nicholson (75), Davidson (77).

Average removals were better from the landfill leachate extract than from the water extract. However, metals were only detectable in the first water extract while metals were detectable in both the first and second landfill leachate extracts. To allow a more equitable comparison of removals from the two different solvents, a second ranking was developed for removals from landfill leachate using only data from the first extract. The ranking was: Anthony (52), Chalmers (58), Davidson (61), Nicholson (61), Kalkaska (68). In this ranking, the average percent removals are less than from the water extract and the relative positions of the soils have changed compared to the ranking based on both extracts. However, because the percent removals are quite close in this last ranking, changes in the relative positions of soils are not as significant as they might be if the differences in removal percentages were larger. The differences in metal removal from different extracts emphasize the point raised earlier in the discussion of the Ni-Cd battery batch study, specifically, detailed studies are needed to define the characteristics of each waste. These characteristics (solubility, pH, etc.) should be the basis for selection and design of disposal sites.

Selection of Soils for Column Studies

One of the main purposes for conducting the batch attenuation studies was to select, from the five soils, the soil with the greatest attenuation capacity and the one with the least capacity so these two could be used in the subsequent column studies.

Considering the rankings of soils in each of the batch studies, it is clear that Davidson was the best soil in nearly all cases. The identity of the soil with the least attenuation capacity is not as clear. Anthony and Kalkaska appear equally often at the bottom of the ranking and about twice as often as Nicholson. The average of the average removal percentages shown in the ten rankings in the various batch studies were: Kalkaska (50), Nicholson (59), Anthony (62).

After considering this information and noting that it was desired to have two soils of different textures (relative amounts of sand, silt, and clay) Kalkaska was selected as the second soil for the column studies.

TABLE 40. SOIL ATTENUATION OF METALS EXTRACTED FROM WATER BASE PAINT
WASTE USING LANDFILL LEACHATE

SOIL TYPE	Percent Removal of Metals by Soil						
	Cd	Cr	Cu	Ni	Zn	Hg	Pb
1. KALKASKA SOIL							
a. 1st Extract							
2 grams soil	44	100	30	100	92	6	86
10 grams soil	52	100	40	100	93	22	92
b. 2nd Extract							
2 grams soil	100	100	12	100	42	77	78
10 grams soil	100	100	23	100	61	82	82
2. CHALMERS SOIL							
a. 1st Extract							
2 grams soil	49	100	0	0	100	69	88
10 grams soil	69	100	0	0	100	69	74
b. 2nd Extract							
2 grams soil	100	100	23	100	54	64	84
10 grams soil	100	100	0	100	93	80	84
3. ANTHONY SOIL							
a. 1st Extract							
2 grams soil	39	100	10	0	72	38	92
10 grams soil	53	100	0	0	95	38	94
b. 2nd Extract							
2 grams soil	100	100	34	100	45	91	81
10 grams soil	100	100	67	100	66	100	83
4. DAVIDSON SOIL							
a. 1st Extract							
2 grams soil	46	100	0	10	100	69	22
10 grams soil	79	100	0	28	100	100	100
b. 2nd Extract							
2 grams soil	100	100	100	100	68	54	84
10 grams soil	100	100	100	100	100	100	82
5. NICHOLSON SOIL							
a. 1st Extract							
2 grams soil	27	100	0	100	100	6	70
10 grams soil	49	100	0	100	100	6	97
b. 2nd Extract							
2 grams soil	100	100	100	100	77	93	85
10 grams soil	67	100	100	100	56	94	80

CONTINUOUS-LEACHING SOIL-COLUMN STUDIES

Preparation of Soil Columns and Leaching Procedures

The continuous-leaching soil-column investigations were conducted using two soils rather than all five described in the batch studies portion of this report; i.e., the soil showing the greatest attenuation (Davidson) and the soil showing the least (Kalkaska). A column height of 10 centimeters was used for the Davidson soil and 21.4 centimeters for the Kalkaska soil (3.7 centimeters inside diameter). The air-dried, prescreened "20 mesh" soil was packed into the appropriate column. A bulk density of 1.52 grams/cubic centimeter was obtained reproducibly with the Kalkaska soil by tamping the column after every 1.5 inches of soil was added. It was far more difficult to obtain a desired field density of 1.6 grams/cubic centimeter with the Davidson soil. It was found that by tamping the Davidson soil after every 1/8 inch was added, accompanied by shear (from twisting the tamper), a field density of 1.49 was finally obtained. Seventy-two columns (36 of each soil) were prepared in that manner and used in the column studies.

Initially, distilled water was added to the top of each of the waste columns, and the waste leachate was passed into the soil columns. A liquid flow rate of 0.5 to 1.5 pore volume per day was desired. The waste leachate penetrated the Kalkaska soil columns very rapidly. It was necessary to nearly close the stopcock at the bottom of the soil column to regulate the flow. On the other hand, penetration of waste leachate through the Davidson soil was so slow that considerable head pressure (7 feet) was necessary to obtain the desired flow rate. The liquid head pressure must be held quite constant for the more permeable soils because as little as a 15 mm change doubles the flow rate through Kalkaska soil. It was extremely difficult to regulate the flow through both of these soil type columns to the desired 0.5 to 1.5 pore volume per day (38.2 milliliters/day for Davidson soil and 88.4 milliliters/day for Kalkaska soil). When operated in a "downflow" configuration, the flow rates varied from 0.25 to 10 pore volumes per day. Other problems encountered were channeling and areas within the soil columns where the soil was completely saturated. Because of these problems, an "upflow" configuration (Figure 11) was used. In addition, the soil column output stopcock (Teflon) was grooved from the bore halfway around the stopcock. The groove was tapered, diminishing in depth as it moved out from the bore. This groove permitted better flow control.

Three columns of each soil were used with each waste leaching solvent combination. Each of the three columns was leached differently. When a metal(s) of interest was detected in the soil column effluent, one of the three columns was removed from the column leaching rack, frozen, sectioned, dried and pulverized and the sections analyzed for metal distribution. The leaching of the two remaining columns continued until additional metals of interest were detected in the soil column effluent. A second column was removed, and processed as previously described. It was felt that this difference in leaching time of the two columns would

show differences in metal distribution as the waste and soil columns were leached and as the waste aged. When the second column was removed, the waste connected to the third column was also removed. This remaining soil column was then leached with just the leaching solvent (water or municipal landfill leachate). The leaching continued until the metals detected in the soil column effluent when the waste was present, showed a decrease in concentration.

Data Treatment

The regression equations derived for the pooled data from the wastes (described in Section 4) were used to obtain the concentrations of each metal presented to the soil columns. The effect of the soil upon this waste leachate is shown in several ways. The soil column output curves and equations were obtained by pooling the observed concentrations of each metal exiting the three columns containing one soil type exposed to a given waste. In making the plots that characterized the wastes, the observed concentration of each metal was plotted versus the cumulative volume of leaching solvent per unit weight of waste. But for comparing soils to each other, the concentration of metal in the solution passing through the soil columns was plotted versus the cumulative volume per unit weight of soil (to compensate for differing weights of soil). The other relation of interest is the fraction of the input concentration that remains in the solution leaving the soil column. To accomplish this, the waste curves could have been replotted expressing the x-axis in terms of volume per unit weight of soil. However, this new set of waste curves was eliminated by making the x-axis the same length as the waste and soil graphs so the relative curve shapes and magnitudes of the concentrations could be readily compared visually, while point by point comparisons can still be obtained by measuring along the x-axis even if the numerical scale is different. Conversion from one scale to another is easily obtained by knowing that the weight of waste employed was 100 grams, the weight of Kalkaska soil was 350 grams, and of Davidson soil 160 grams.

Because the areas under both sets of curves represent total micrograms of metal, integrals may be obtained from the equations and compared directly to obtain attenuation factors or other measures that require quantities in or out of the soil.

The R-square values for the polynomial approximation of the pooled data from the waste columns and soil columns were large enough that a single curve could be used to represent the amount of each metal applied to each soil and a single curve could be used to represent the output of each metal in the effluent from the three columns of the same soil. These polynomial approximations (curves) were integrated to determine the total amount of each metal applied to (IN) and released from (OUT) each soil. After dividing each by the weight of soil in the column (different weights of soil were used in the Davidson and Kalkaska columns) OUT was divided by IN to give the relative fraction of each metal not retained by the soil. This negative measure of the soils attenuation capacity is presented as a bar graph for each metal and soil.

Results and Discussion

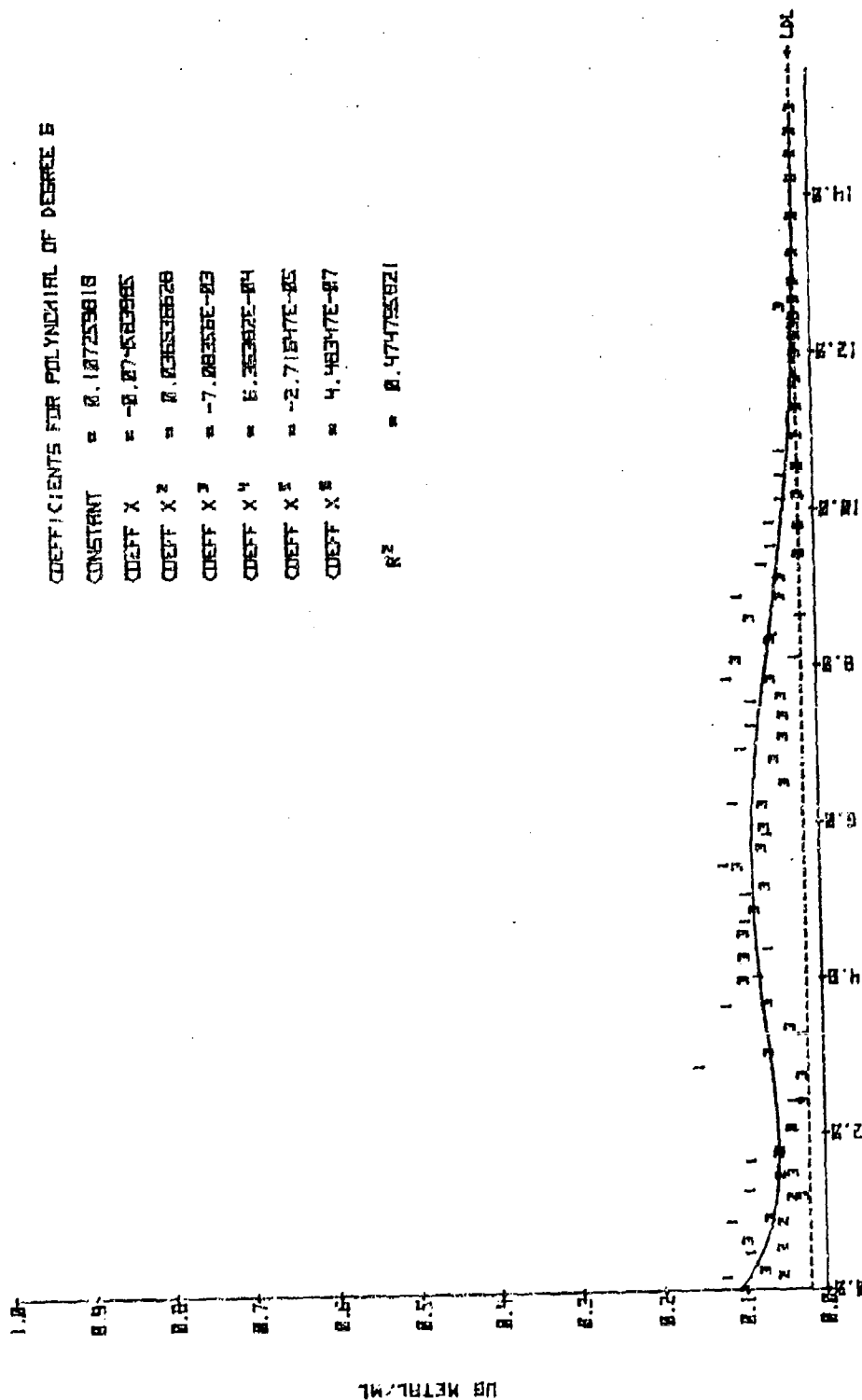
Electroplating Waste--

One hundred grams of the electroplating waste described in Section 4 was packed into columns. The solvents, water and municipal landfill leachate, were passed through the columns to generate a waste leachate. This waste leachate was then passed through columns of Davidson and Kalkaska soil (see Figure 11). Both the waste leachate and the effluent from the soil columns were sampled periodically for analysis. Results for waste and municipal landfill leachate are discussed separately below.

Water Extracts--Amounts of cadmium, copper, nickel, and zinc leached from the electroplating waste by water are shown in Figures 12 through 15 (Section 4). These figures show the variation in metal concentrations with time in the waste leachate applied to both the Davidson and the Kalkaska soil columns. The concentrations of these metals in the effluents from the Davidson soil are shown in Figures 71 through 74. No chromium was found in the soil column effluent (nor was it found in waste leachate samples). The plots show that the principal metal leached from this waste by water is cadmium. The drinking water level (0.01 milligram/liter) was exceeded continuously from the commencement of leaching until a cumulative volume of 10.7 milliliters/gram of soil was reached. At this point, the waste was removed and the single remaining soil column was leached with water. The cadmium concentration in the soil column leachate dropped to the detection limit (0.02 milligram/liter). This indicates that the cadmium removed by the soil was retained quite strongly. This will be more thoroughly discussed in a supplemental report.

Copper, nickel and zinc did not exceed the drinking water levels (no drinking water standard has as yet been set for nickel). It is interesting to note that more zinc was leached from the soil column than was applied in the leachate from the waste column. This was the case with several of the wastes. Zinc is ubiquitous in soils and the environment. It is readily leached (in low concentrations) by water. Though no attempt has been made to distinguish between zinc from the waste and zinc from the soil, it is apparent that the majority of the zinc in the soil column effluents originates from the soil. Although only part of the zinc comes from the waste, the high concentrations of zinc in the soil column effluents are a result of the waste-soil interaction.

Concentrations of cadmium, copper, nickel, and zinc in the effluents from the Kalkaska soil columns are shown in Figures 75 through 78. As with Davidson soil, only the cadmium leached from this waste sample exceeded the water standard, the other metals did not. However, the Kalkaska soil allowed considerably more of each metal to pass than did the Davidson soil.



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.107259818

COEFF X = -0.07483985

COEFF X² = 0.036536628

COEFF X³ = -7.08355E-03

COEFF X⁴ = 6.36382E-04

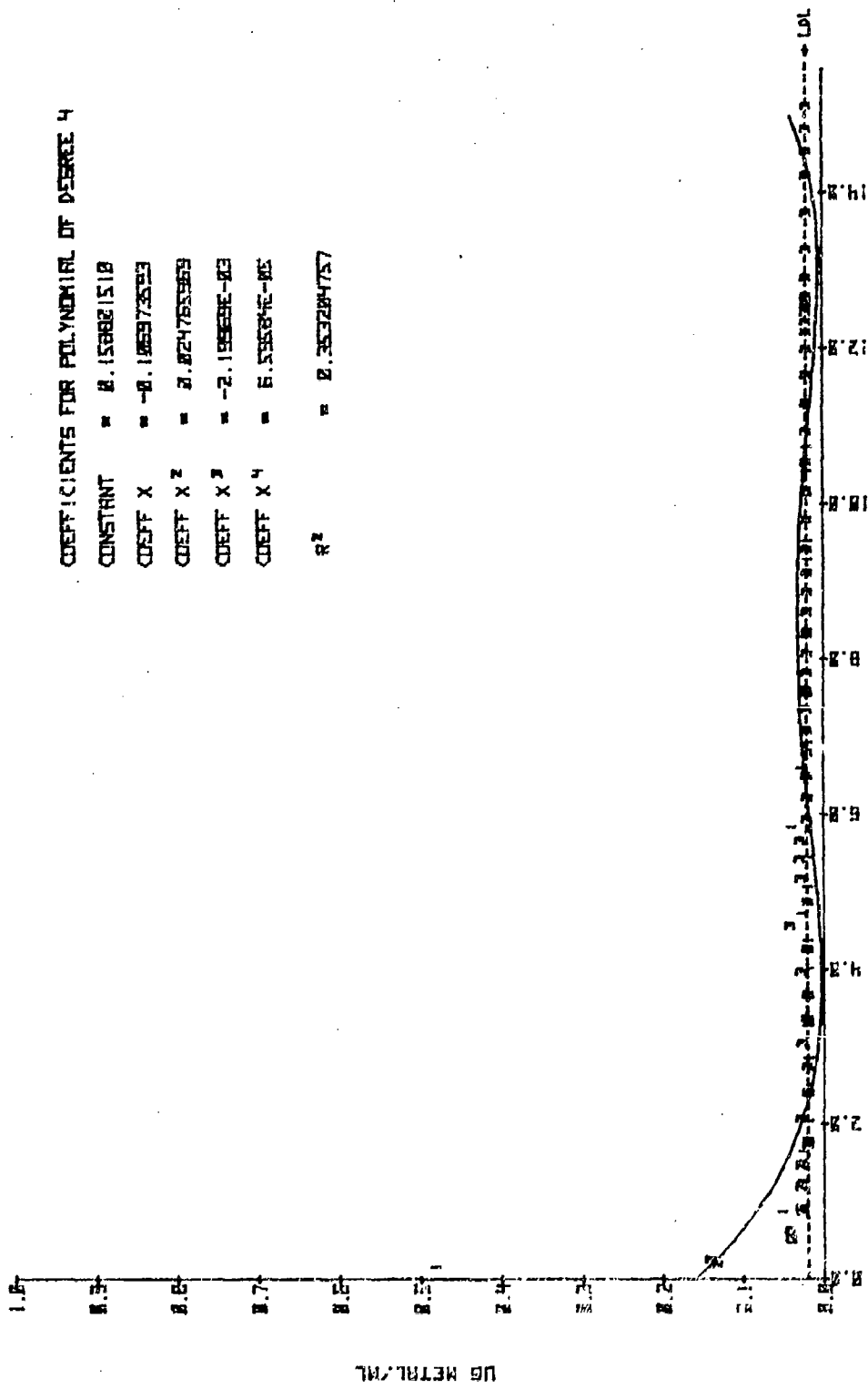
COEFF X⁵ = -2.71647E-05

COEFF X⁶ = 4.48347E-07

R² = 0.47475821

CUM VOLUME (ML/GM SOIL)

FIGURE 71: CADMIUM LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY WATER



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 4

CONSTANT = 0.1588021510

COEFF X = -0.105973593

COEFF X² = 0.024755359

COEFF X³ = -2.19559E-03

COEFF X⁴ = 6.55558E-05

R² = 0.953204757

CUM VOLUME (ML/CM SOIL)

FIGURE 72: COPPER LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY WATER

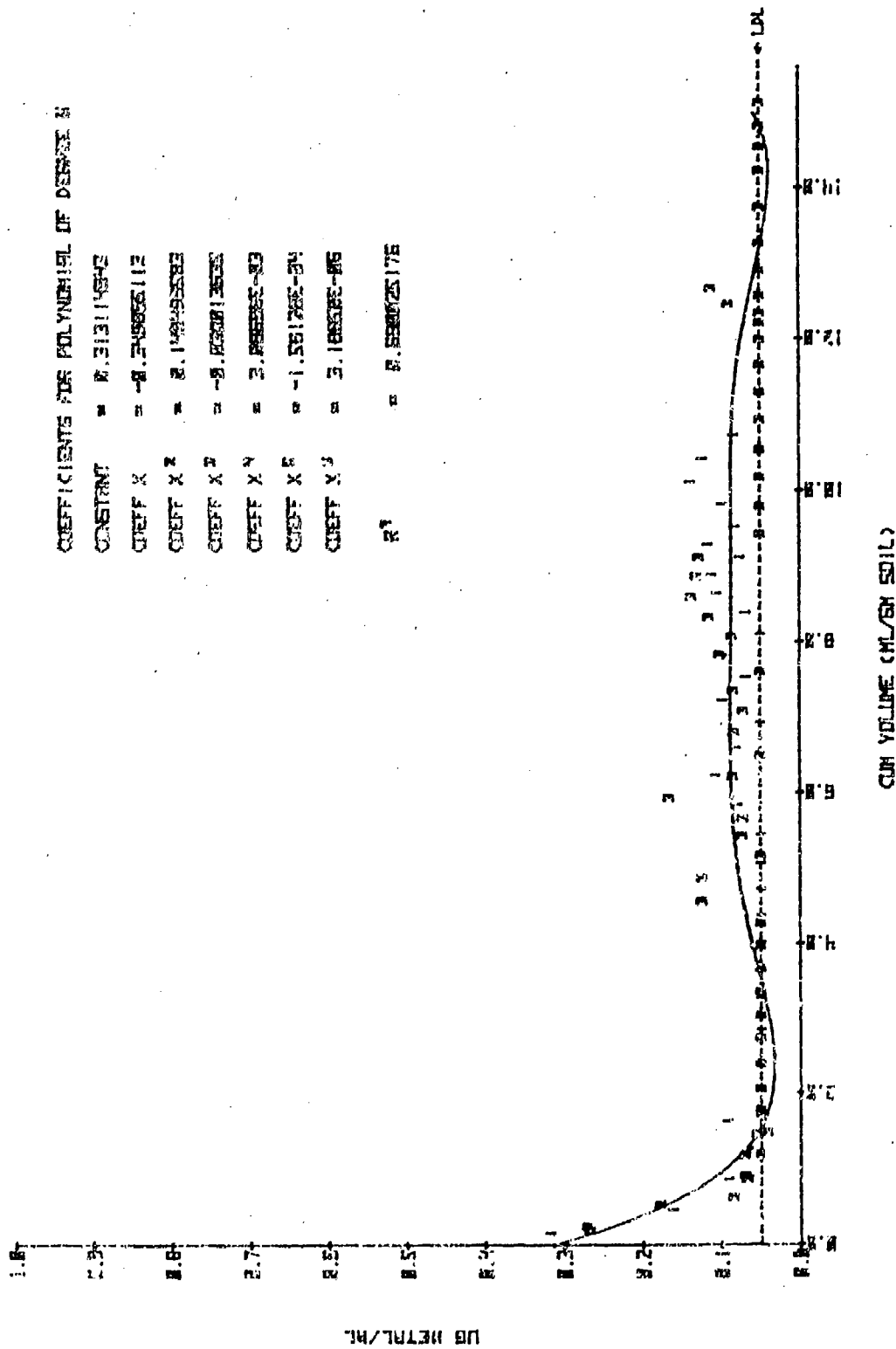
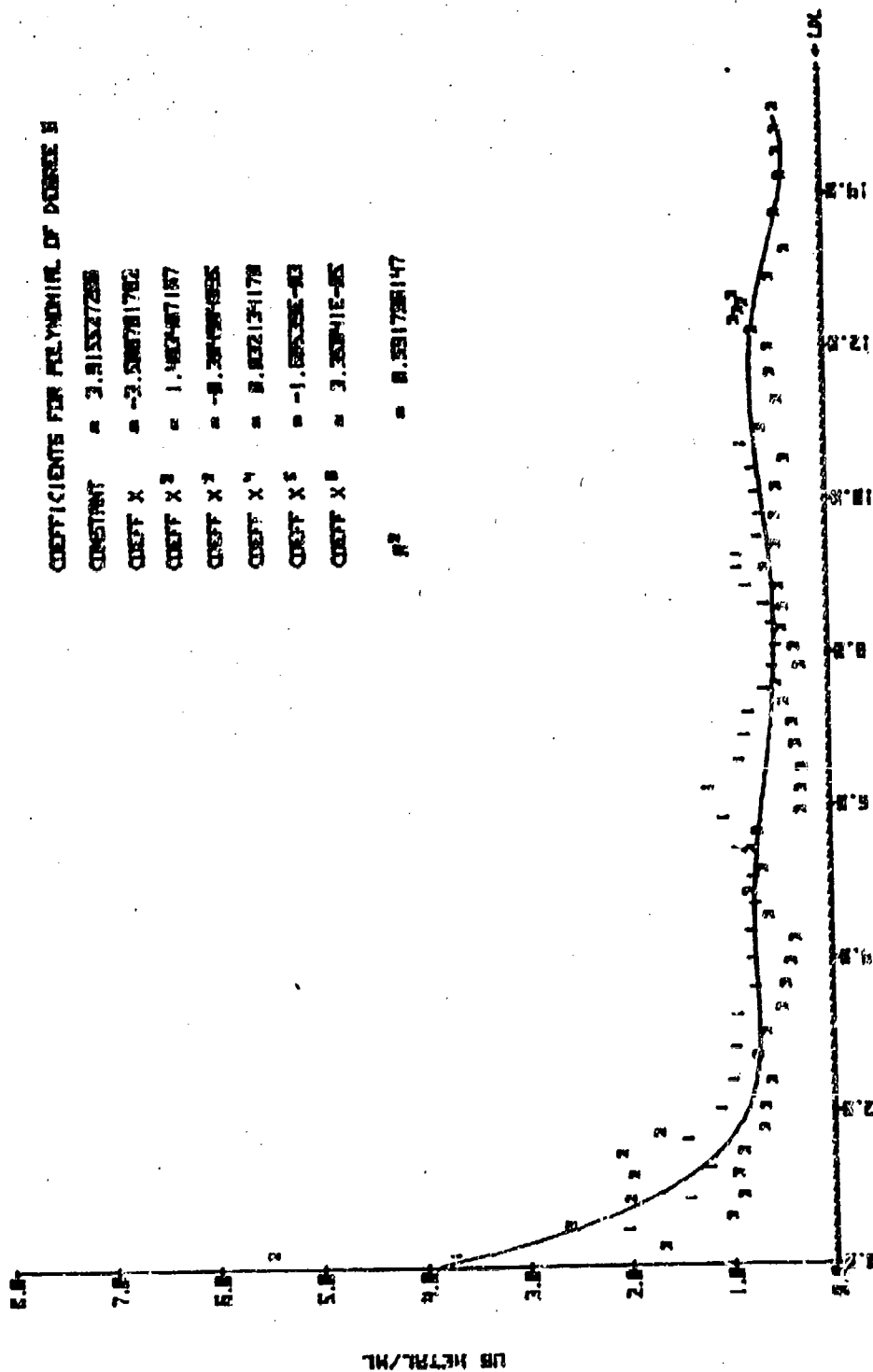


FIGURE 73: NICKEL LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY WATER



CUP VOLUME (ML/SH SOIL)

FIGURE 74 : ZINC LEACHED FROM ELECTROPLATING WASTE & DRYEDSON SOIL BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 8

CONSTANT = 2.53742578
 COEFF X = -2.392748525
 COEFF X² = 2.163775564
 COEFF X³ = -2.633155975
 COEFF X⁴ = 2.148551-23
 COEFF X⁵ = 5.851215-25
 COEFF X⁶ = -2.354272-25
 R² = 0.578183425

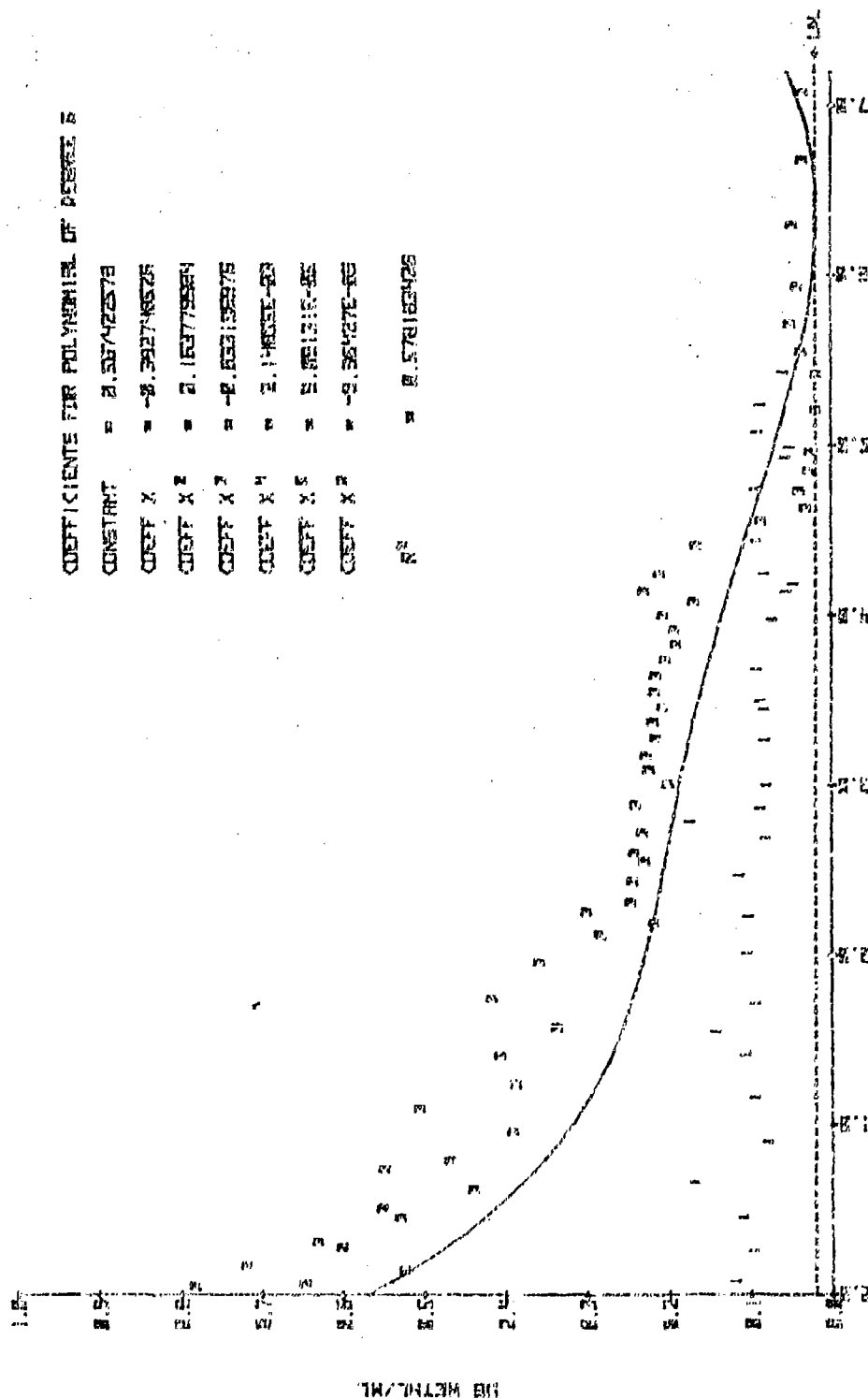
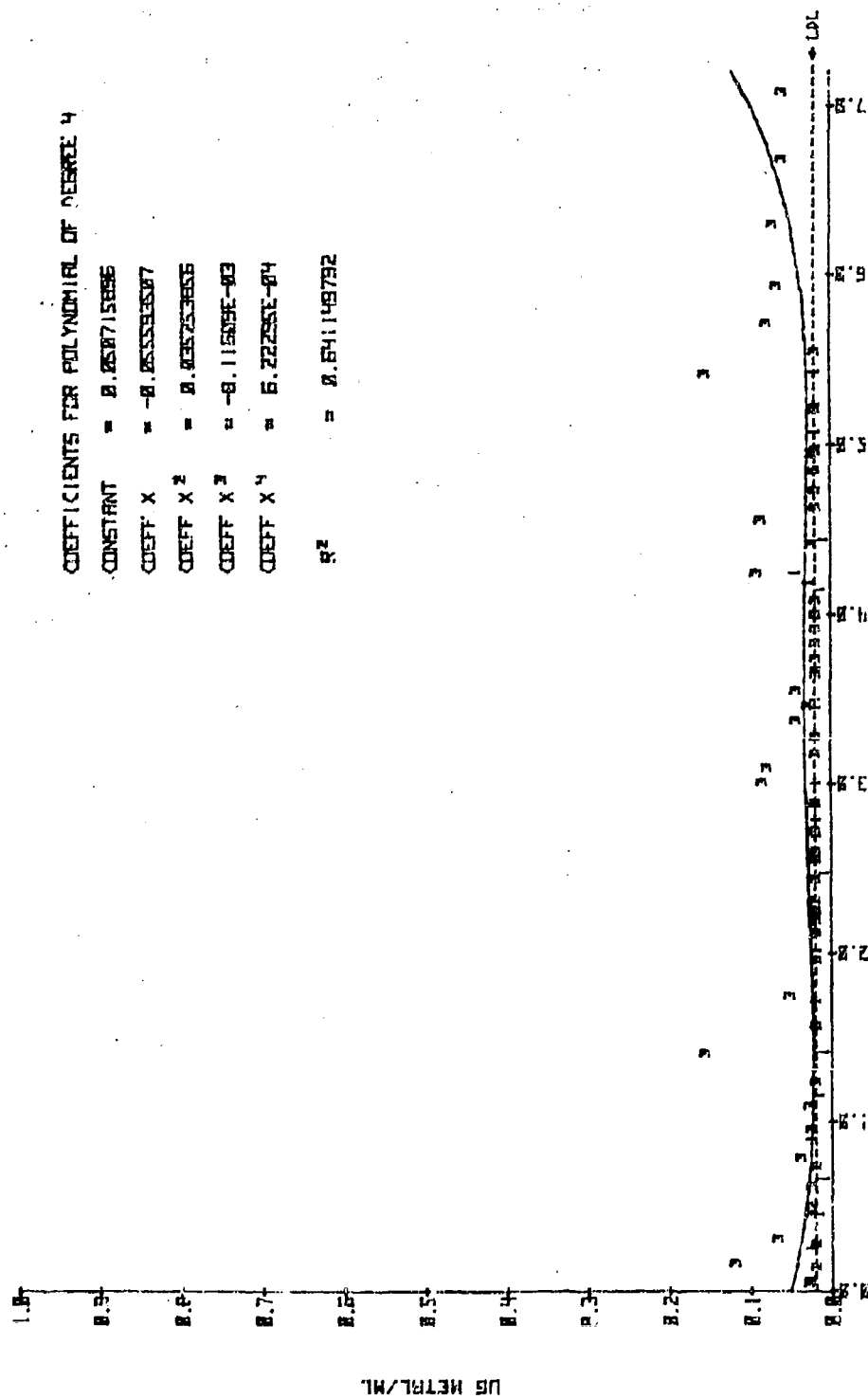


FIGURE 75: CADMIUM LERCHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY WATER



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 4

CONSTANT = 0.050715896

COEFF X = -0.055535007

COEFF X² = 0.035753655

COEFF X³ = -0.11509E-03

COEFF X⁴ = 6.22255E-04

R² = 0.641149792

CUM VOLUME (ML/G SOIL)

FIGURE 76: COPPER LEACHED FROM ELECTROPLATING WASTE & KAILASKA SOIL BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

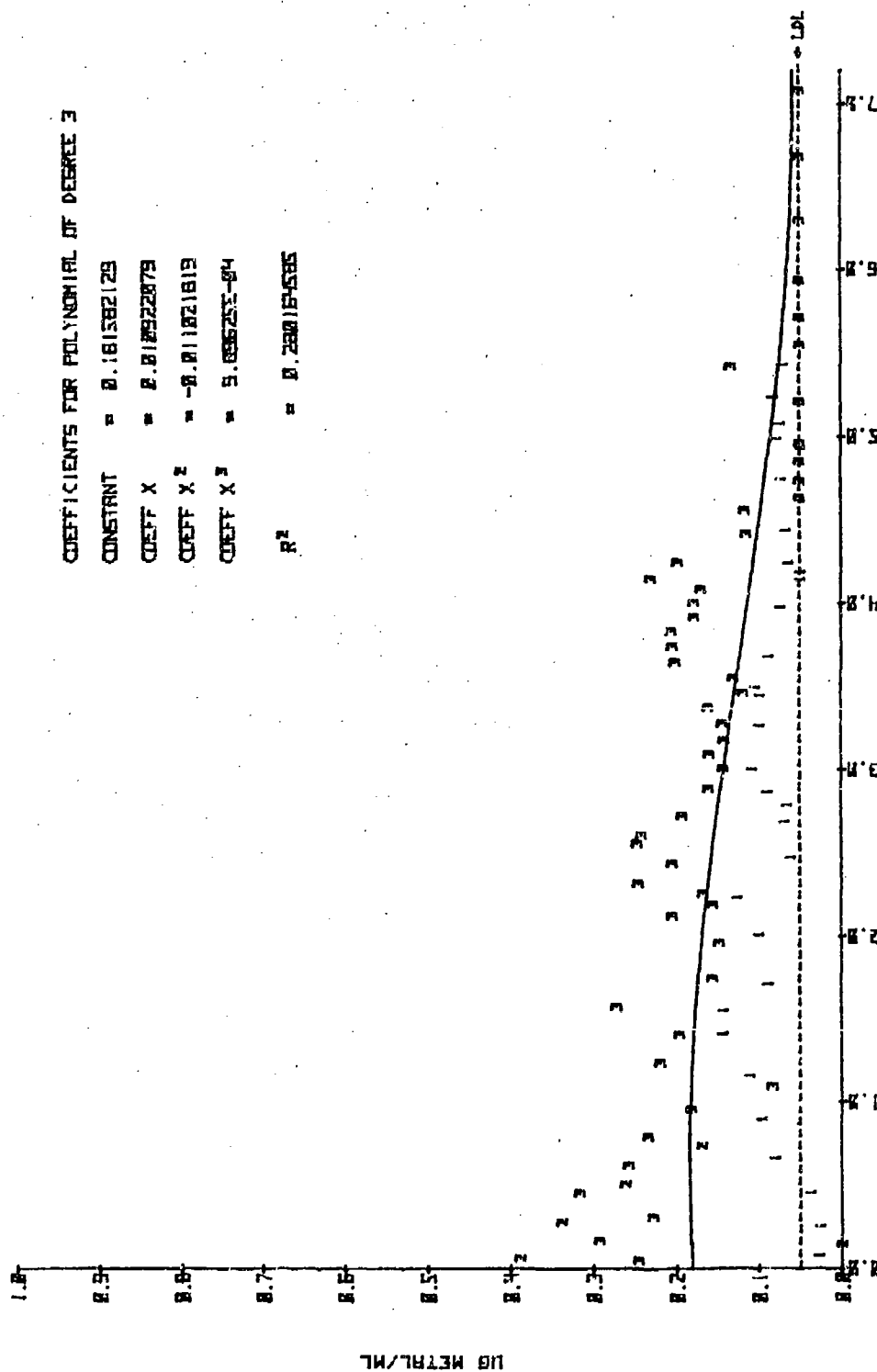
CONSTANT = 0.161562129

COEFF X = 0.010922079

COEFF X² = -0.011021819

COEFF X³ = 0.000255-014

R² = 0.230154585



CUM VOLUME (ML/GM SOIL)

FIGURE 77: NICKEL LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY WATER

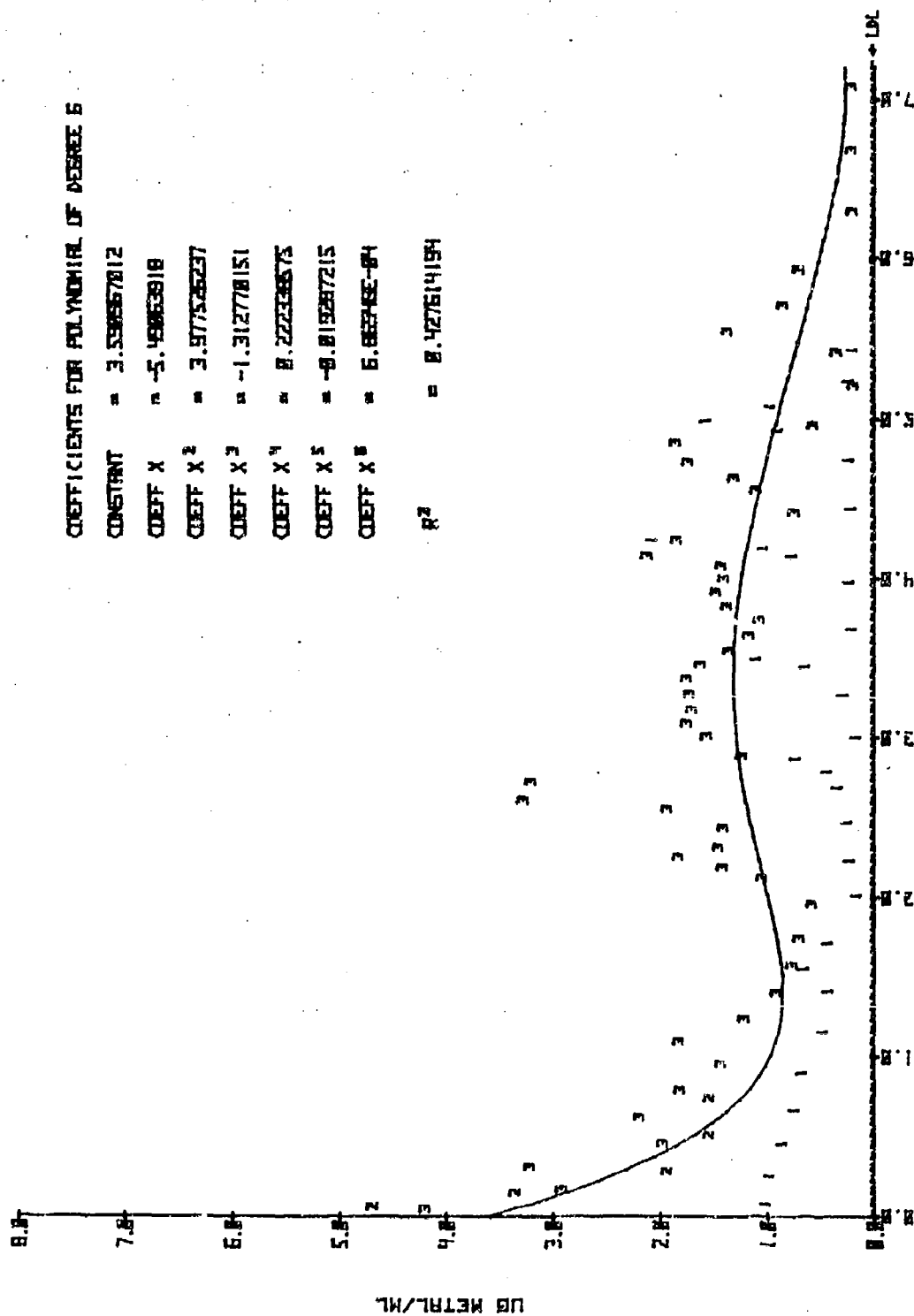


FIGURE 78 : ZINC LERCHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY WATER

Figure 79 shows, in histogram form, the fraction of the input of each metal (microgram/gram soil) from the water leaching of the electroplating waste that passes through each soil. The calculation expressed in the histogram compares the attenuation by both soils at the same total weight of a metal.

The figure shows that Davidson soil was considerably more effective in removing cadmium, copper, and nickel from the waste leachate than was Kalkaska soil. Both soils released zinc with Kalkaska soil releasing slightly more than Davidson soil.

Landfill Leachate Extract--Amounts of cadmium, copper, nickel, and zinc leached from the electroplating waste by landfill leachate are shown in Figures 18 through 21 (Section 4). These figures show the variation in metal concentration with time in the waste leachate applied to both the Davidson and Kalkaska soil columns. Note that because of plugging problems much lower volume of leachate per gram of soil was applied than to the columns where water was used as the leaching solution.

The concentration of cadmium, copper, nickel, and zinc from the Davidson soil are shown in Figures 80 through 83. Both cadmium and zinc appeared in the soil column effluents in concentrations exceeding the drinking water standard. As has been discussed earlier, the source of the zinc in the soil column effluents cannot be clearly established. The municipal landfill leachate contained substantial amounts of zinc (20 milligrams/liter) so the zinc in the soil column effluents could have come from the municipal landfill leachate, the electroplating waste, or the soil or partially from all three of these sources. Nickel was also found in substantial concentrations, but no drinking water standard is available. The copper results were so sporadic that no attempt was made to fit an equation. Only the concentration found in each sample was plotted.

As was noted above, only a small volume of liquid passed through the waste and soil columns. The municipal landfill leachate caused the soil or waste columns to partially plug. It was observed that as the leachate aged, precipitates formed even in a few hours. The reservoir was changed daily because the leachate came in contact with air on the leaching rack. This could not be avoided because if carbon dioxide was used to purge the reservoir, the gas was desorbed from the leachate in the glass lines carrying it from the reservoir to the columns causing a gas bubble blockage in the system.

The concentrations of cadmium, chromium, copper, nickel, and zinc in the effluents from the Kalkaska soil are shown in Figures 84 through 88. As with the Davidson soil, cadmium, chromium, nickel and zinc appeared in the soil column effluents in high concentrations.

D= DAVIDSON

K= KALKASKA

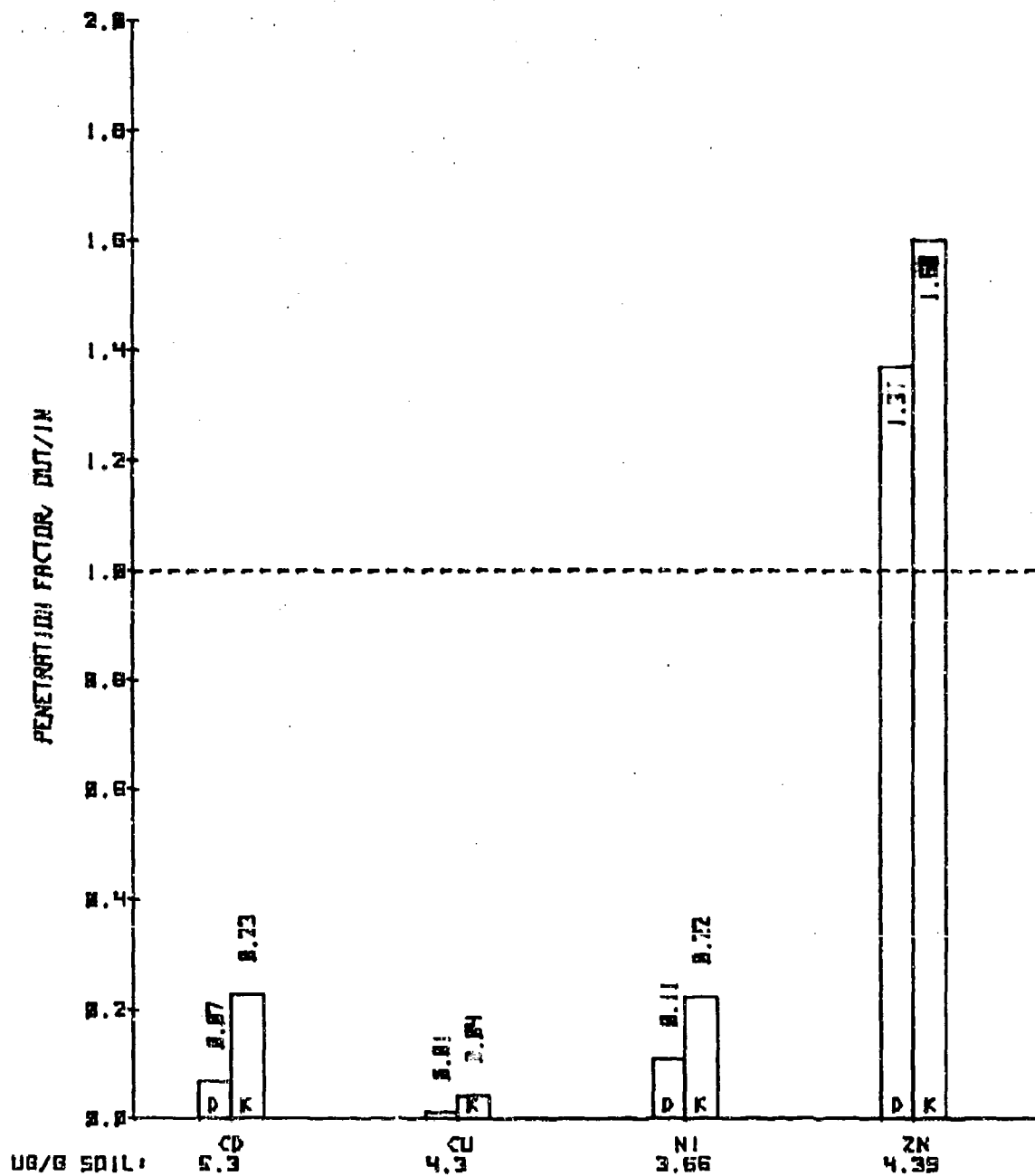


FIGURE 79: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A WATER EXTRACT OF ELECTROPLATING WASTE

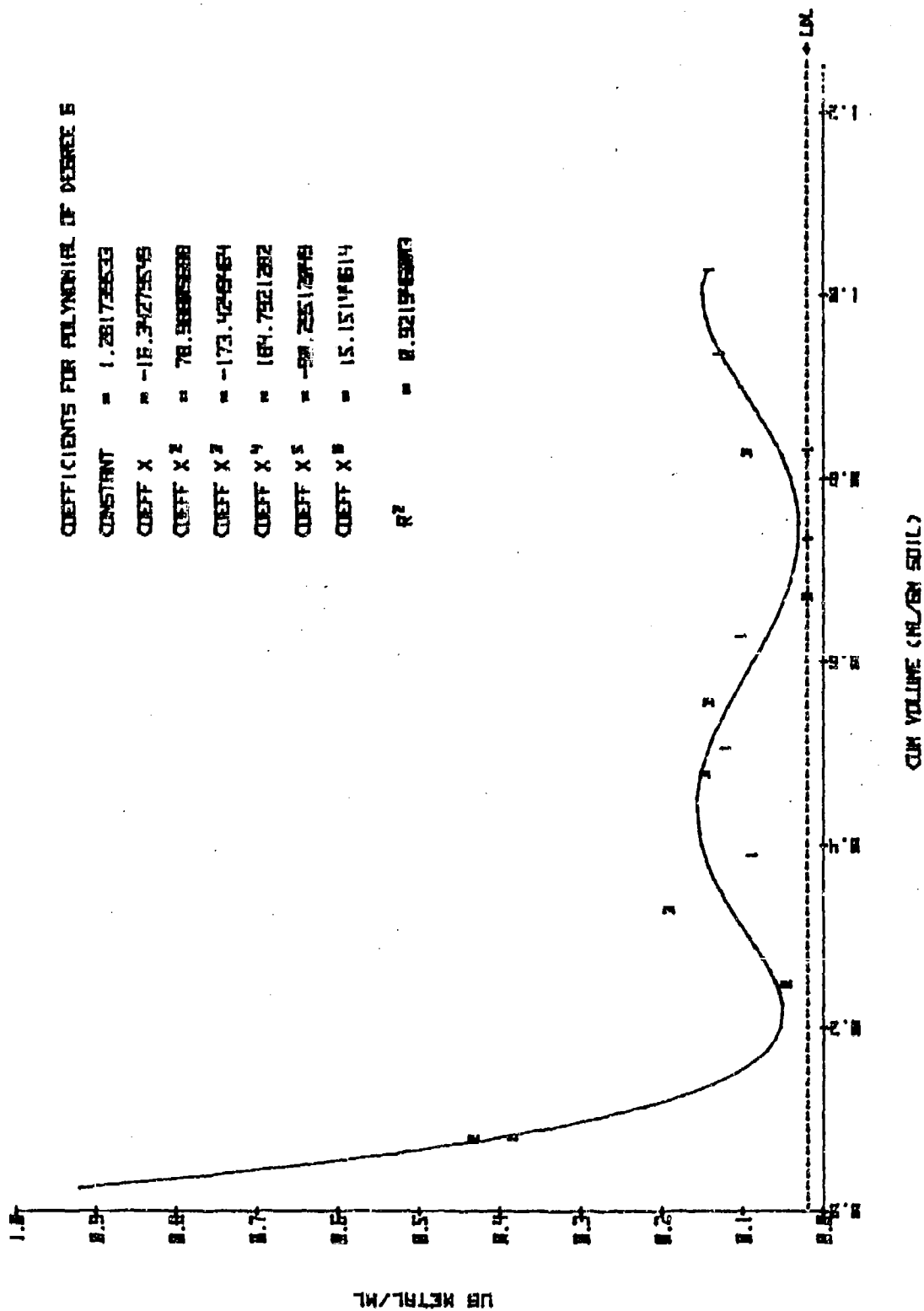


FIGURE 80: CADMIUM LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

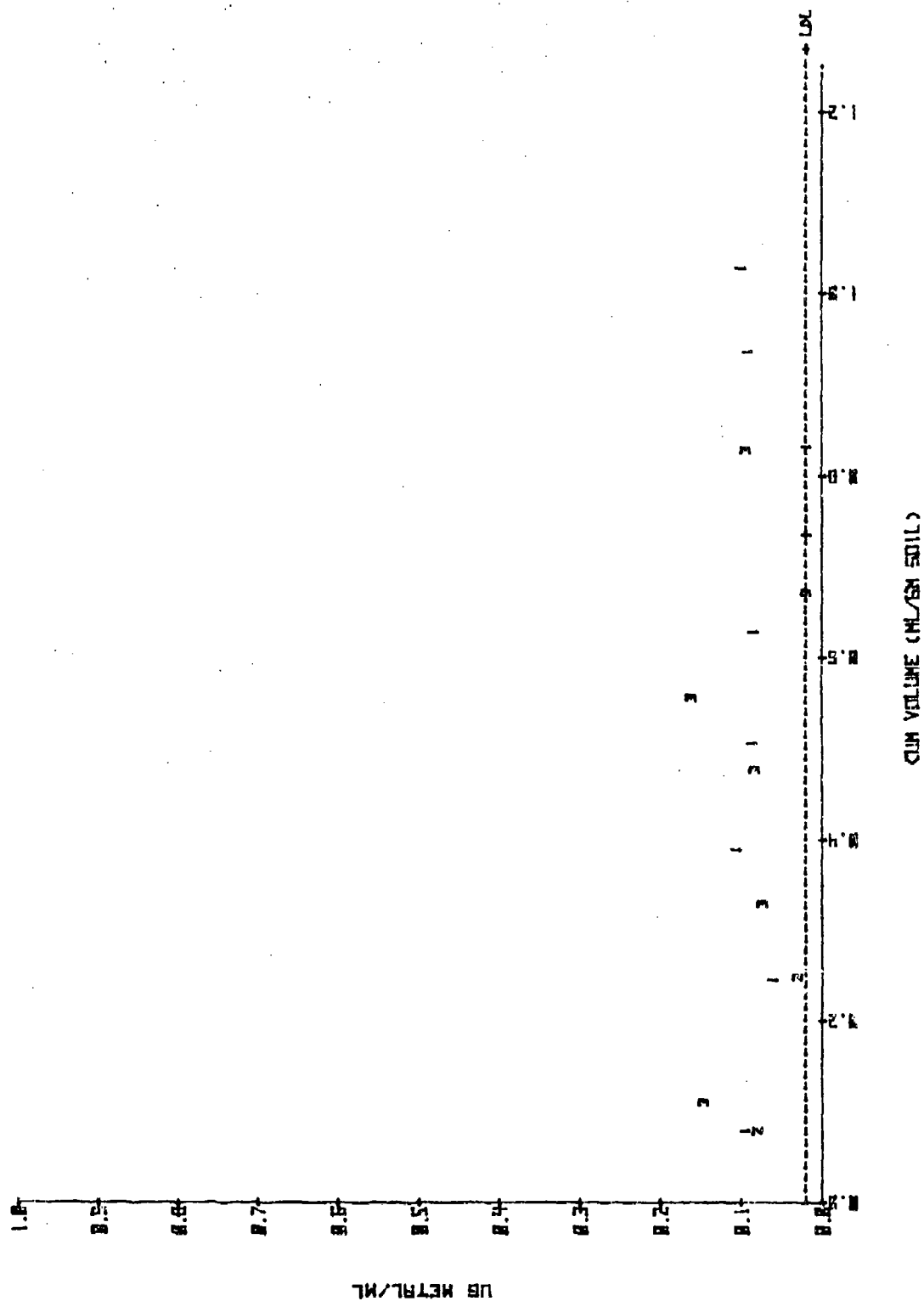


FIGURE 81: COPPER LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

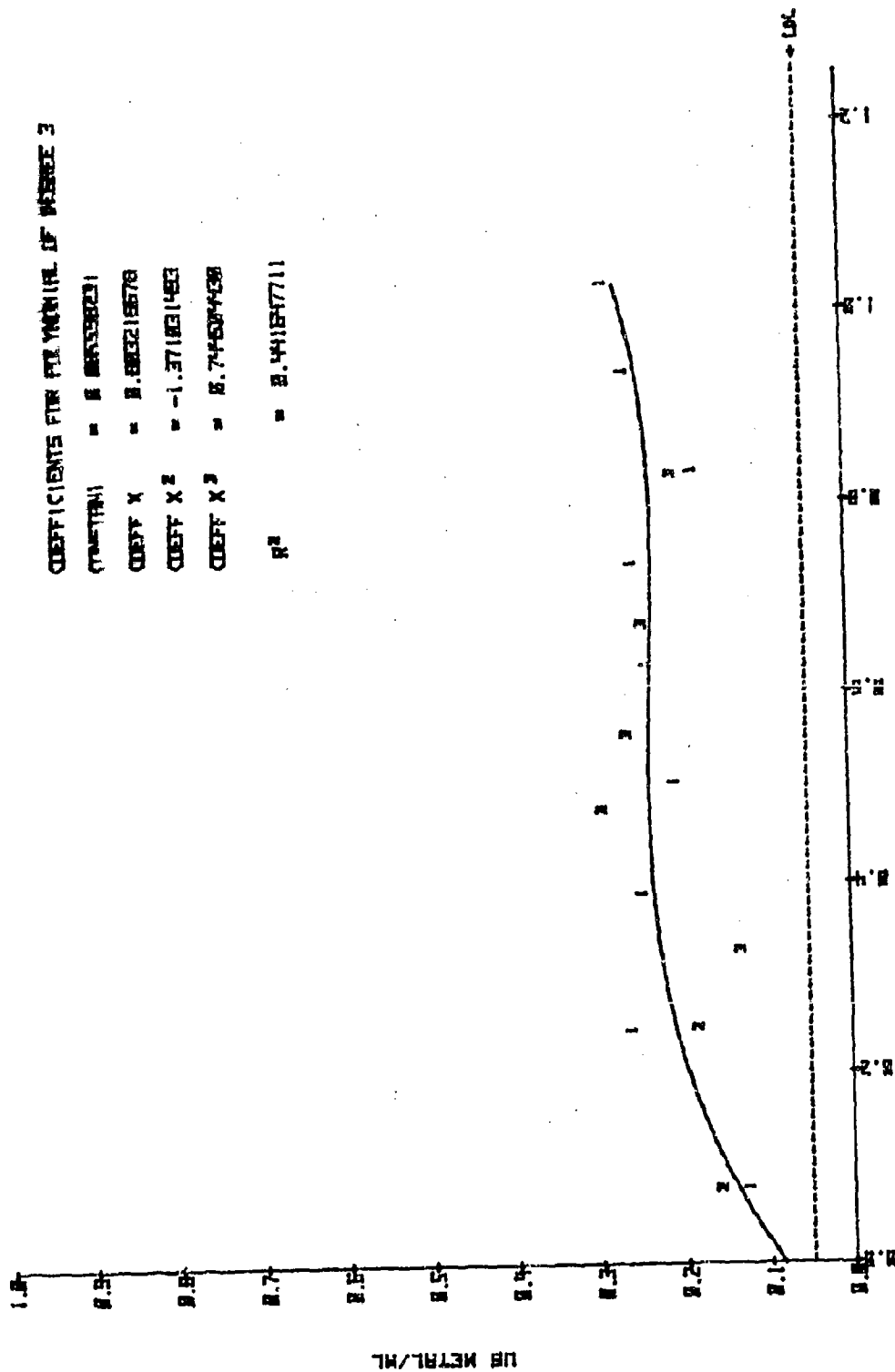


FIGURE 82 : NICKEL LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

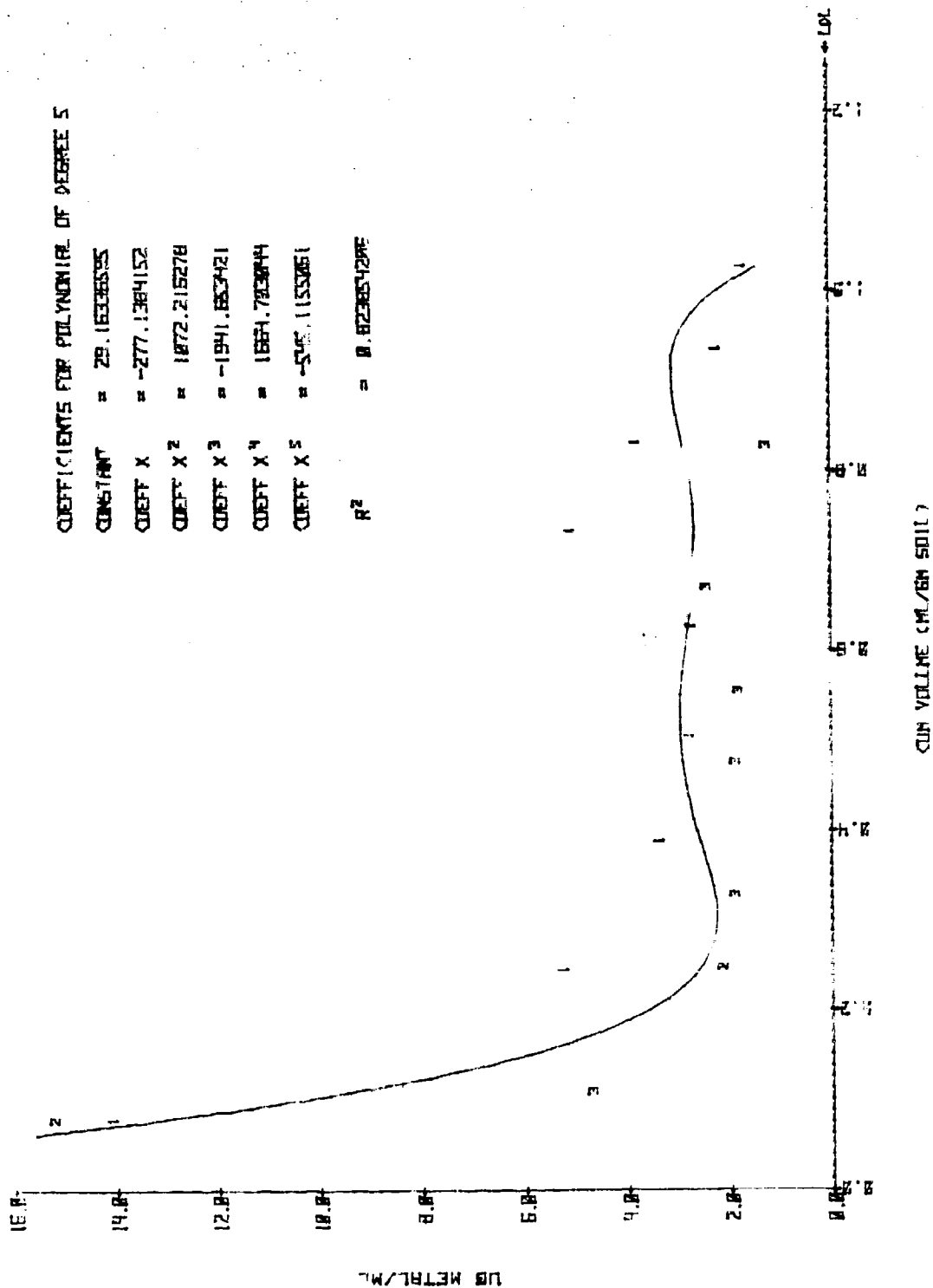
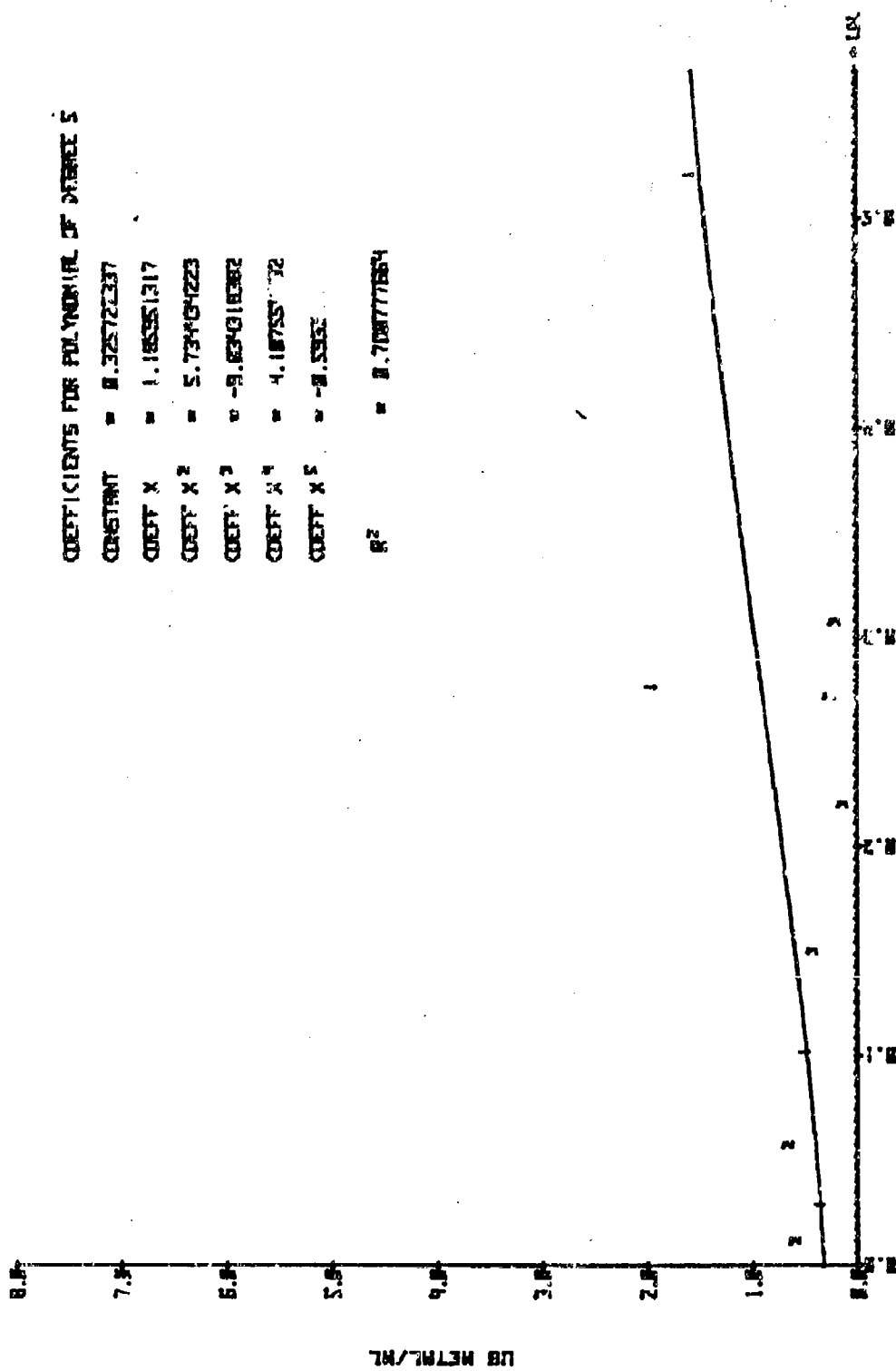


FIGURE 83 : ZINC LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.32572237

COEFF X = 1.185351317

COEFF X² = 5.73404223

COEFF X³ = -9.634318362

COEFF X⁴ = 4.18755112

COEFF X⁵ = -0.5333

R² = 0.708777854

CM VOLUME (CM³/CM² SOIL)

FIGURE 84 : CADMIUM LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

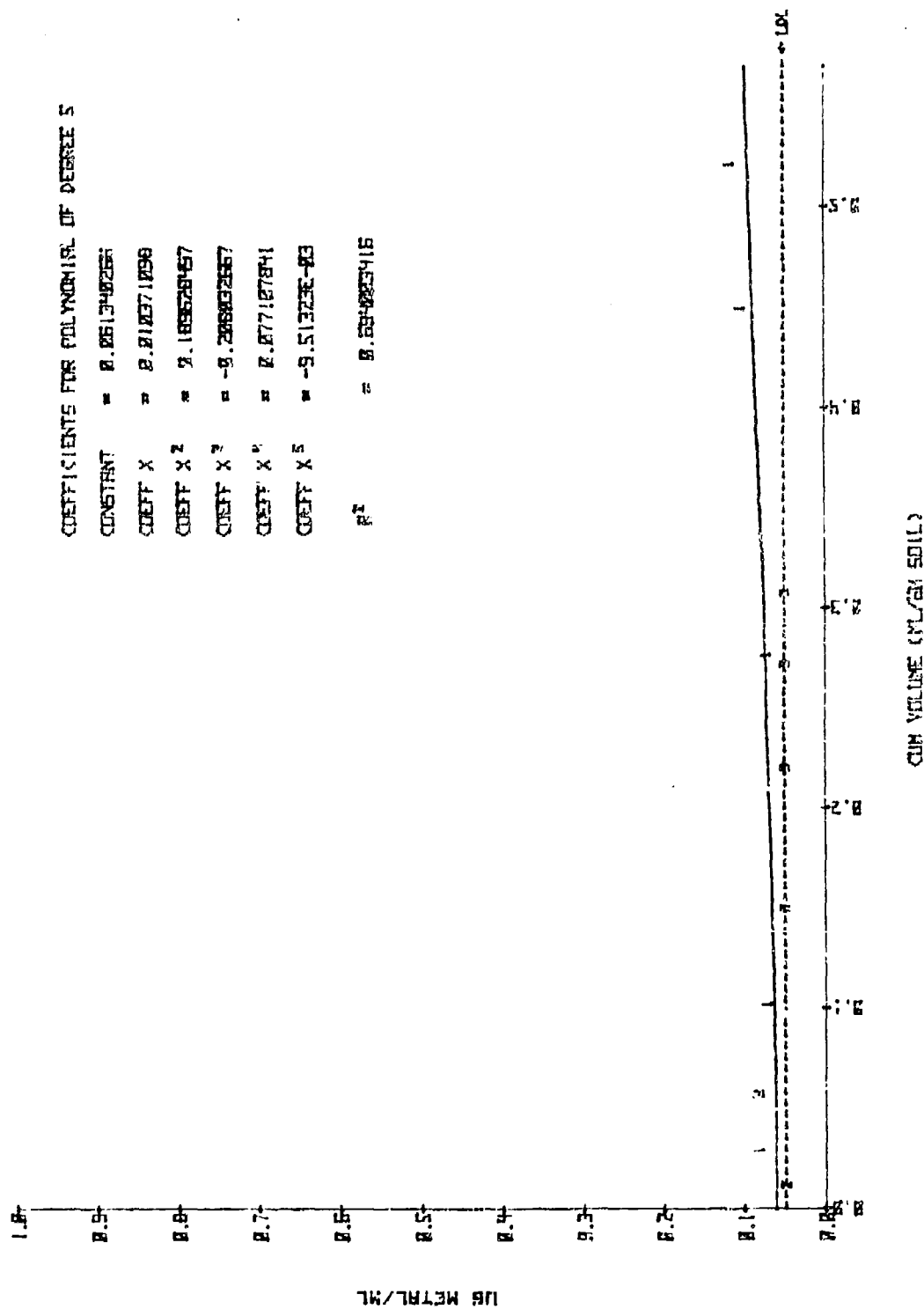
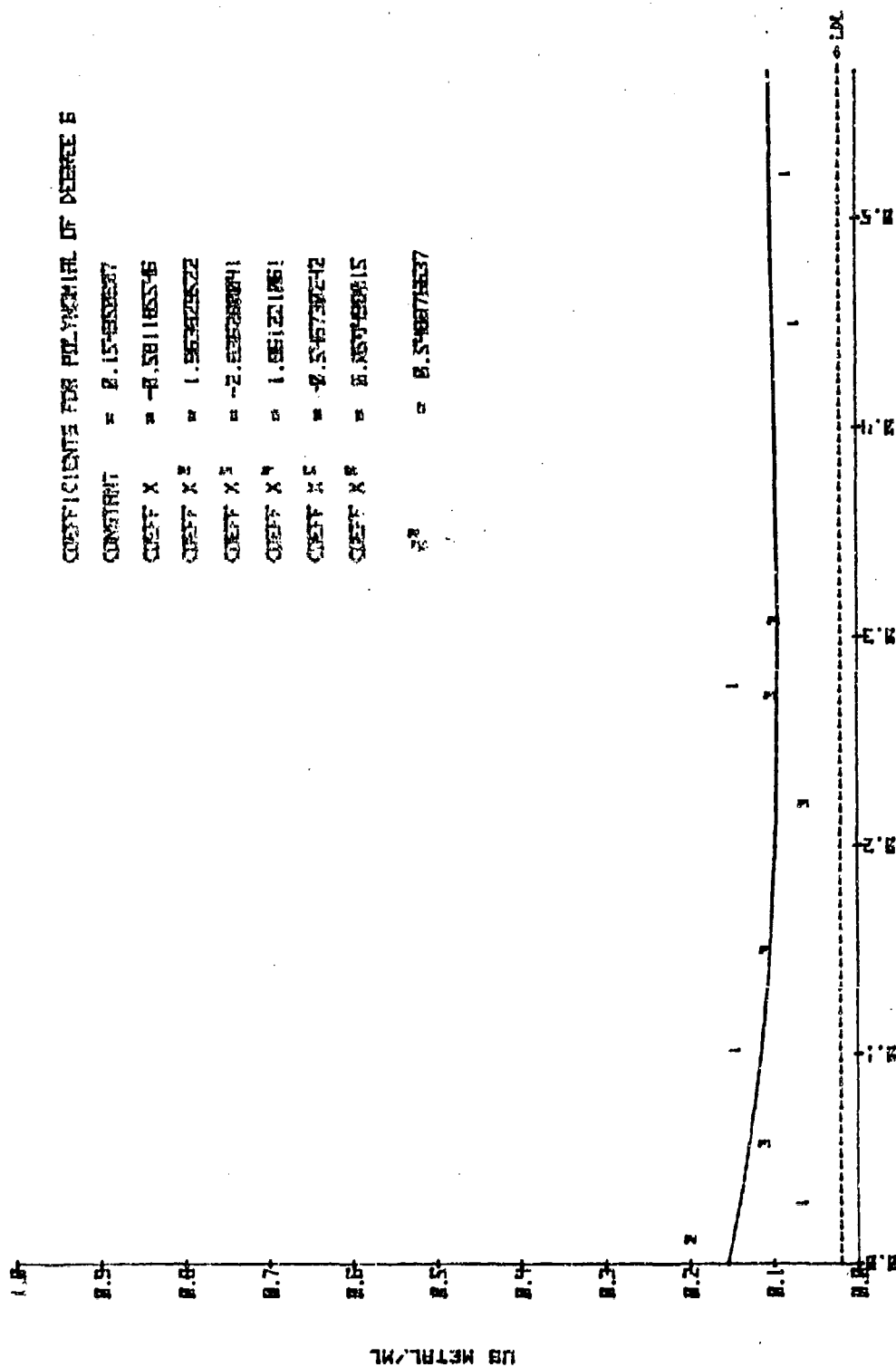


FIGURE 85: CHROMIUM LEACHED FROM ELECTROSLATING WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



CUM VOLUME (ML/GM SOIL)

FIGURE 86 : COPPER LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

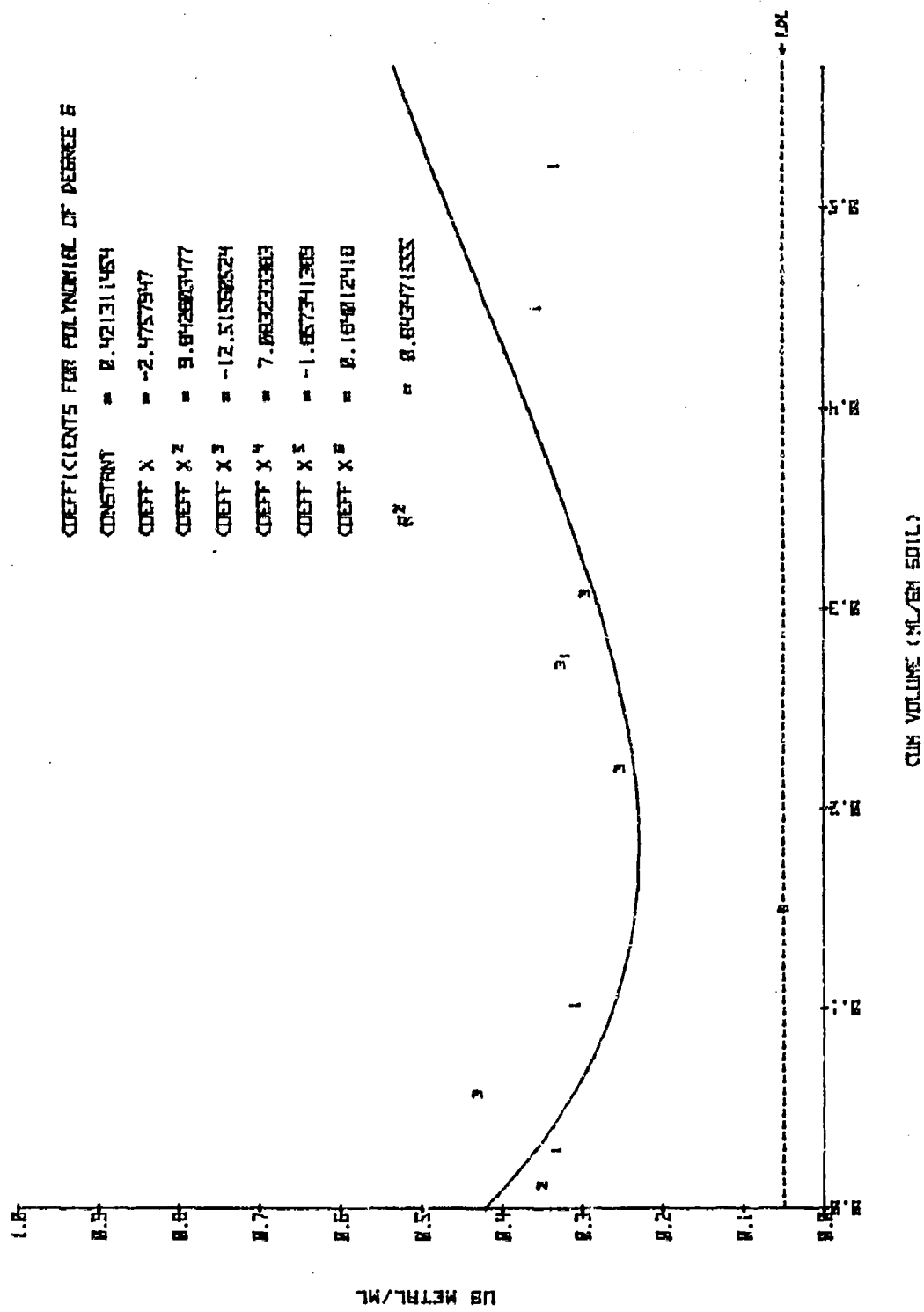


FIGURE 87 : NICKEL LERCHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY LANDFILL LERCHATE

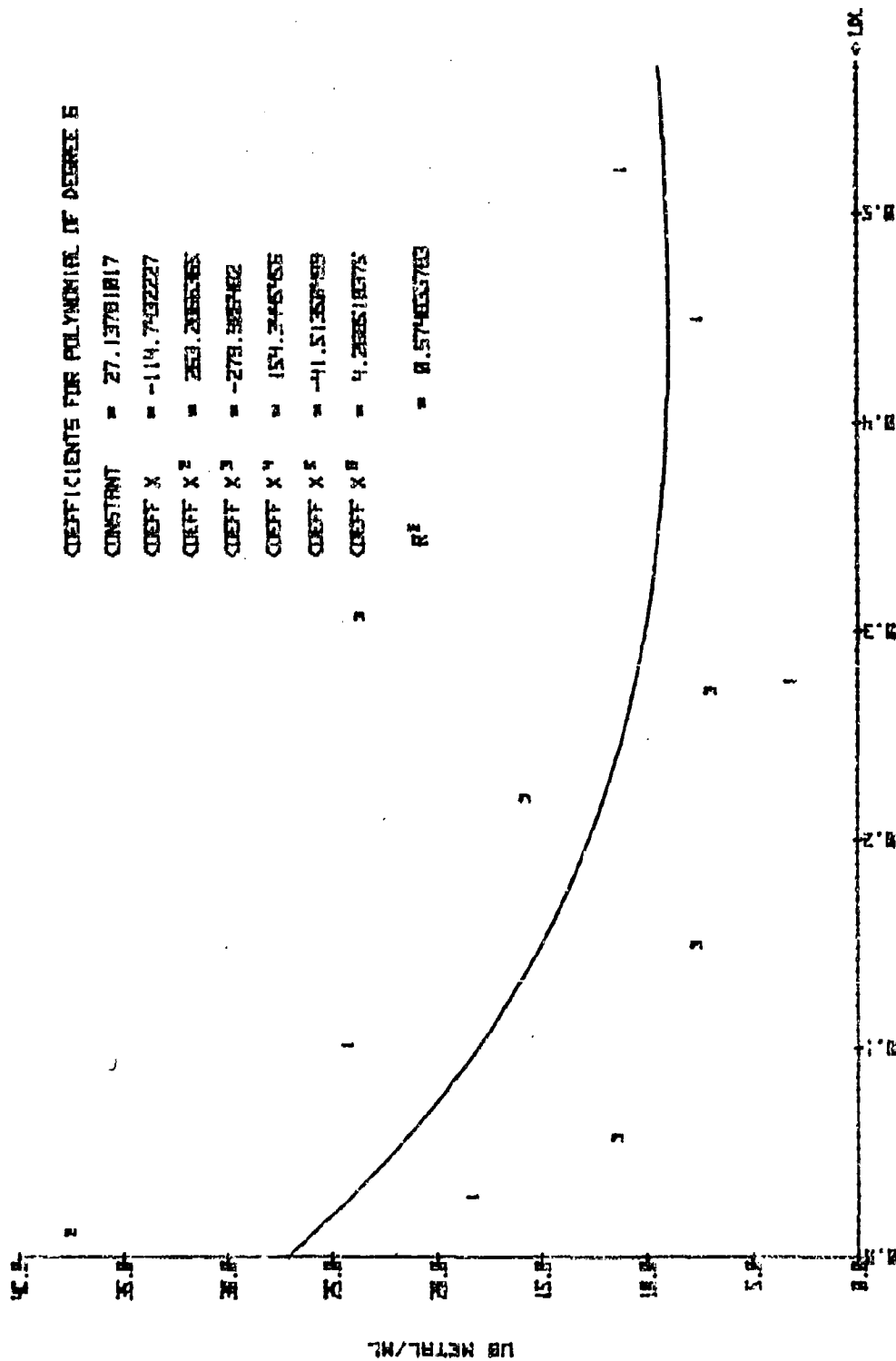


FIGURE 88: ZINC LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

Concentrations of copper in the soil column effluents were low, and it appears this metal will not leach from the waste in concentrations as high as the other metals.

Figure 89 shows in bar graph form the fraction of the input of each metal that passed through each soil. As was noted in the discussion of the water extract column studies, the retention capacities of soils differed as a whole and for specific metals.

It should be noted that the data shown in Figure 89 are not a sophisticated enough tool to be used as the sole basis for judging a soil's removal capacity. Refinements are being considered that would make data displays such as Figures 79 and 89 (the bar graphs in the water and landfill leachate sections) more useful tools for assessing the performance of combinations of wastes, soils, and leaching solutions. These refinements will likely be included in a supplemental report and will involve normalizing the data so that the amount of leaching solution and metal applied per unit weight of soil are comparable. At first glance, it would appear that water leaching of the waste and soil produces higher metal concentrations than if municipal landfill leachate is used. However, if Figures 71 through 78 and 80 through 88 are reviewed, it can be seen that the columns leached with water were leached for a much longer period and with a much larger volume of waste leachate. In addition, the concentration of the metals found in the municipal landfill leachate solution after it had passed through the soil columns was higher than if water was used as the leaching solvent.

pH and Conductance Measurements--Figures 90 through 97 are plots of pH and conductance of the soil effluent samples. Both Davidson and Kalkaska soils and both solvents (water and landfill leachate) are included. The electroplating waste leachate, produced by water leaching, slightly raised the pH of the soil effluent as compared to the pH of soil control column leached by just water, but it did not change the relative pH of the two soils. Kalkaska was still considerably more acid than Davidson.

The conductance of the initial increments of effluent from both soils was very high, indicating removal of soluble ions from the soil and/or penetration of soluble species, other than the metals of interest, from the waste. The conductance decreased rapidly as soluble materials in the waste and the soil apparently were depleted.

The landfill leachate caused pronounced changes in the pH of the soil column effluents. The pH of the Davidson soil samples was still higher than the Kalkaska samples but the difference between the two was significantly less than when water was used as the leaching solution. Landfill leachate is apparently a strongly buffered solution and was able to affect the soil pH even after passage through the moderately alkaline electroplating waste.

D= DAVIDSON

K= KALKASKA

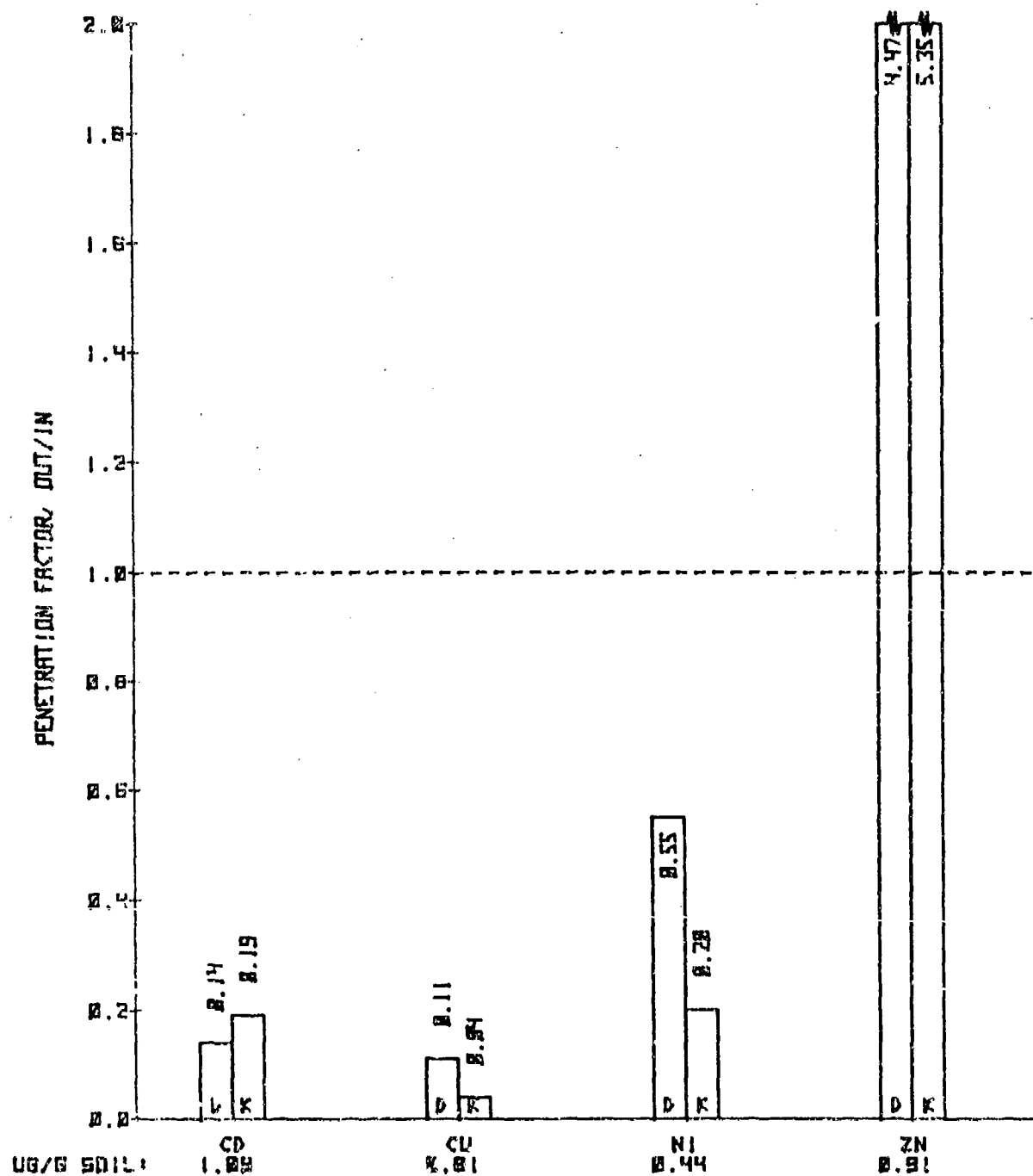
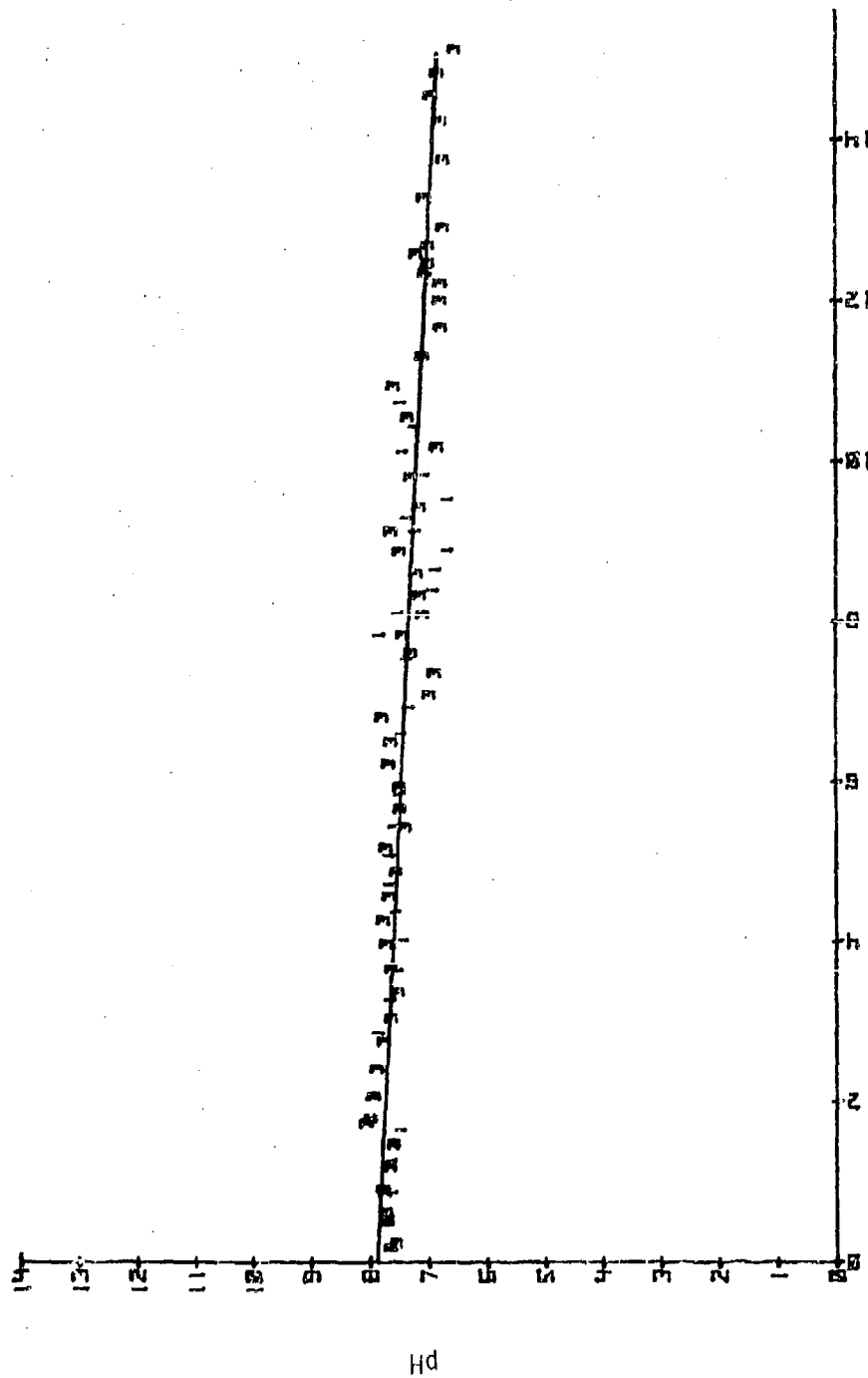


FIGURE 89: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A LANDFILL LEACHATE EXTRACT OF ELECTROPLATING WASTE



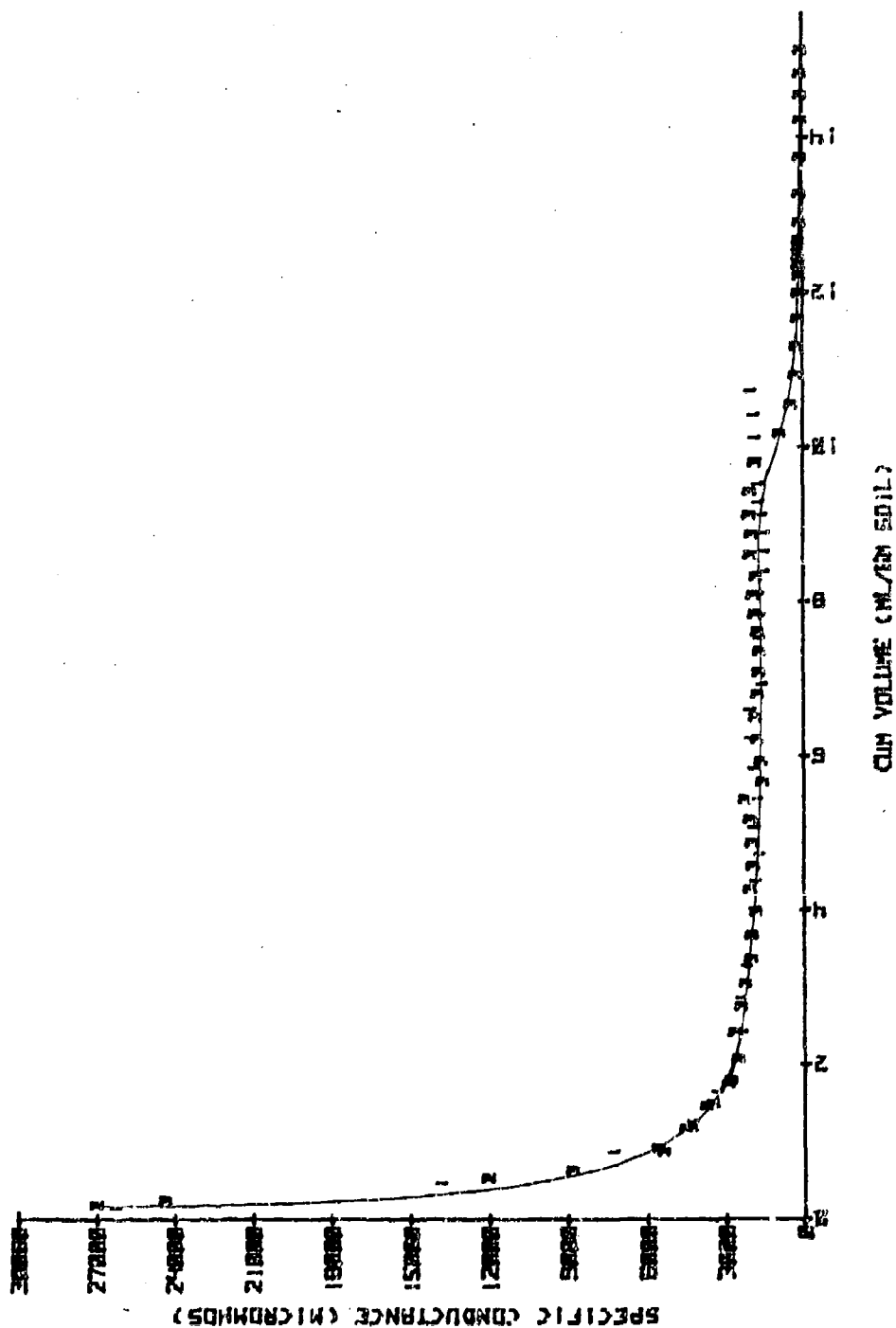


FIGURE 91: CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY WATER

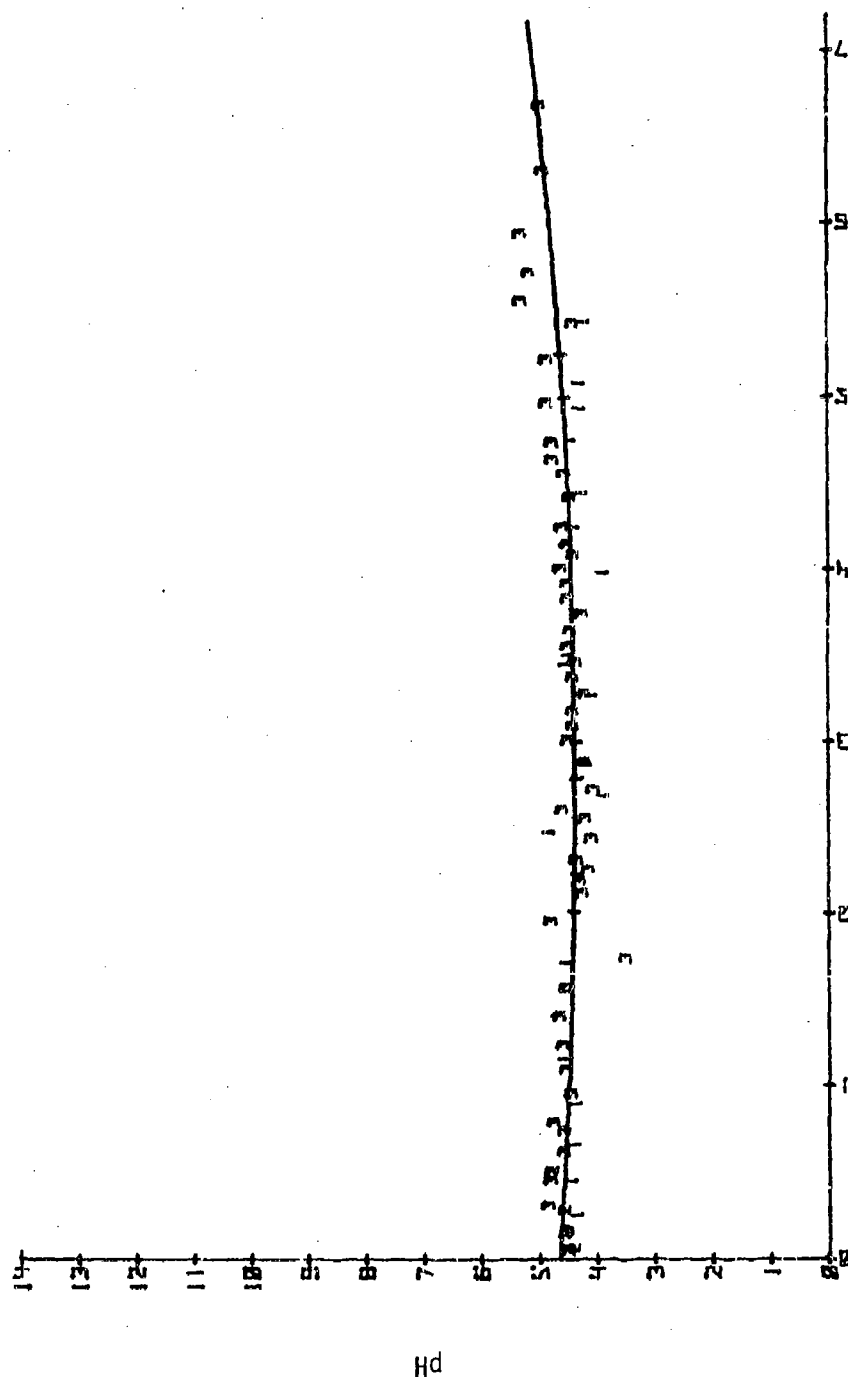


FIGURE 92 : pH OF SOLUTION LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY WATER

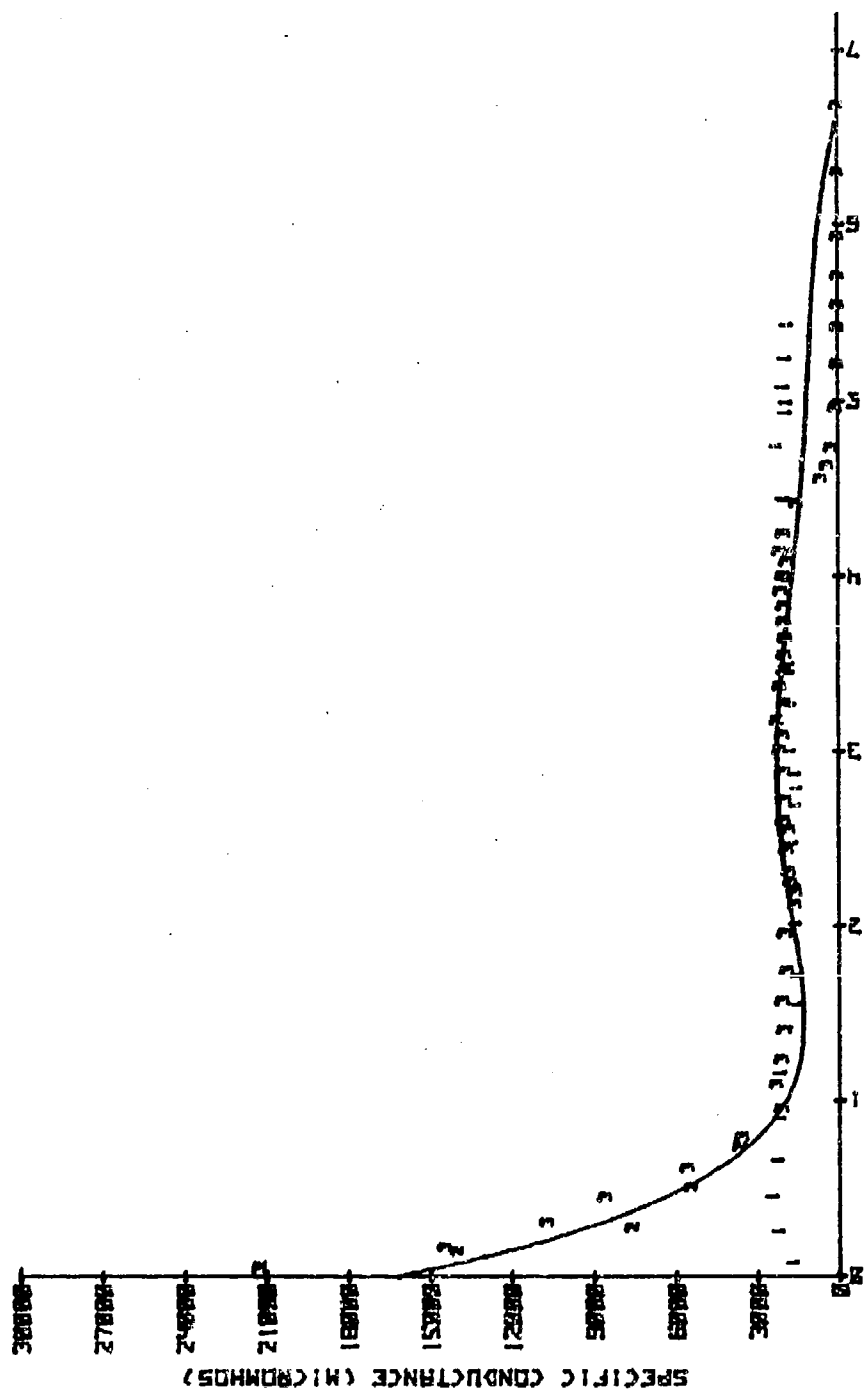


FIGURE 93 : CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY WATER

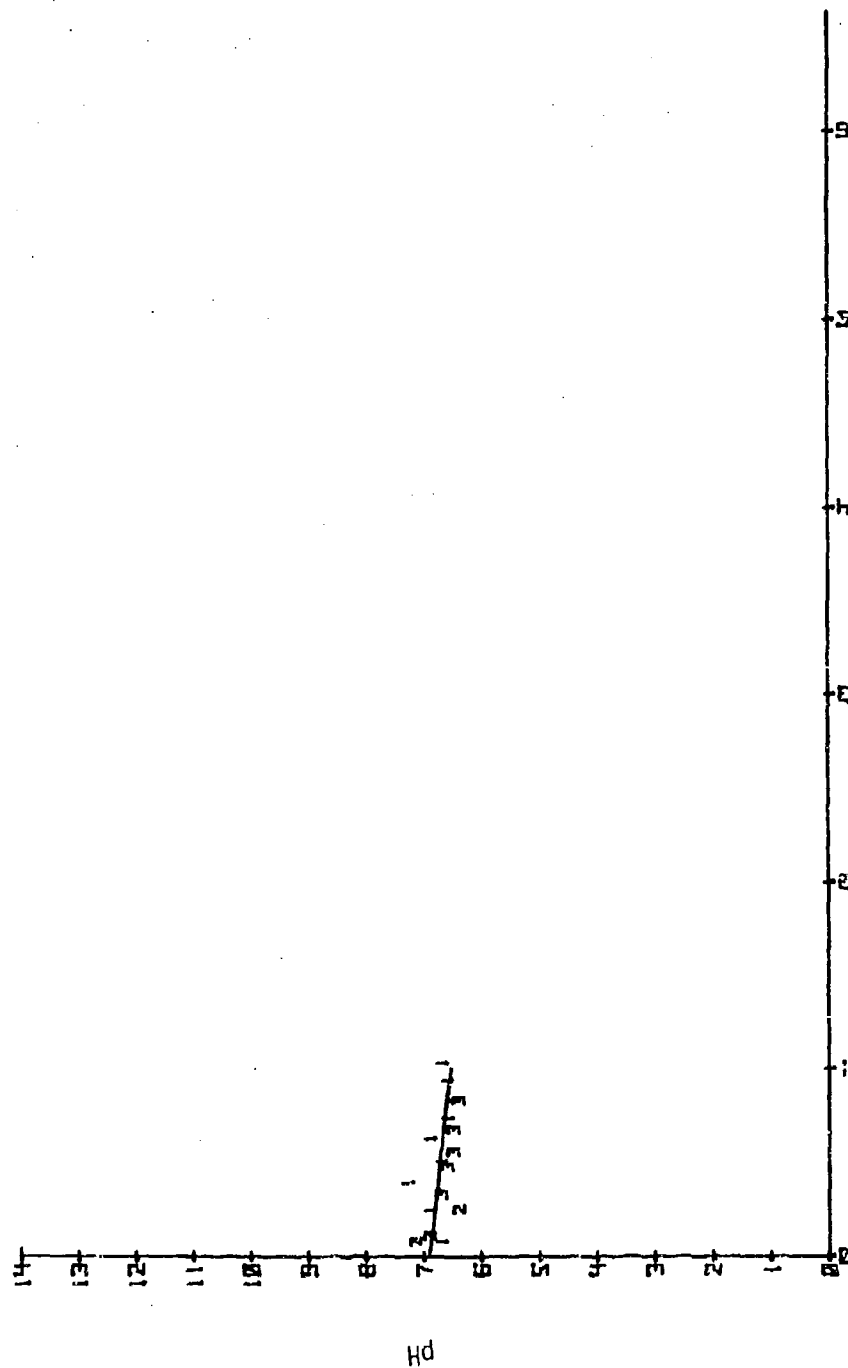


FIGURE 94 : pH OF SOLUTION LEACHED FROM ELECTROPLATING
WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

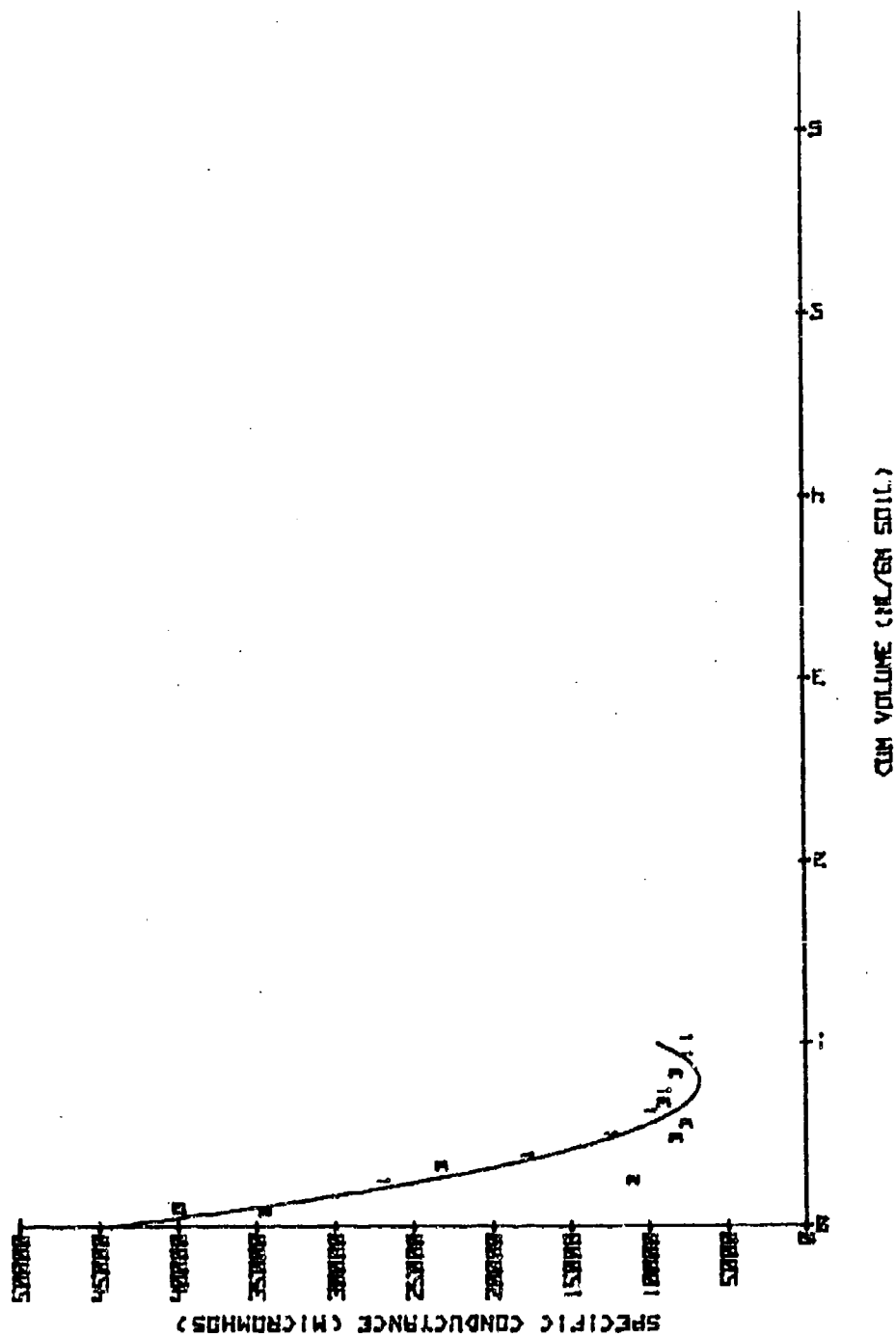


FIGURE 95 : CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

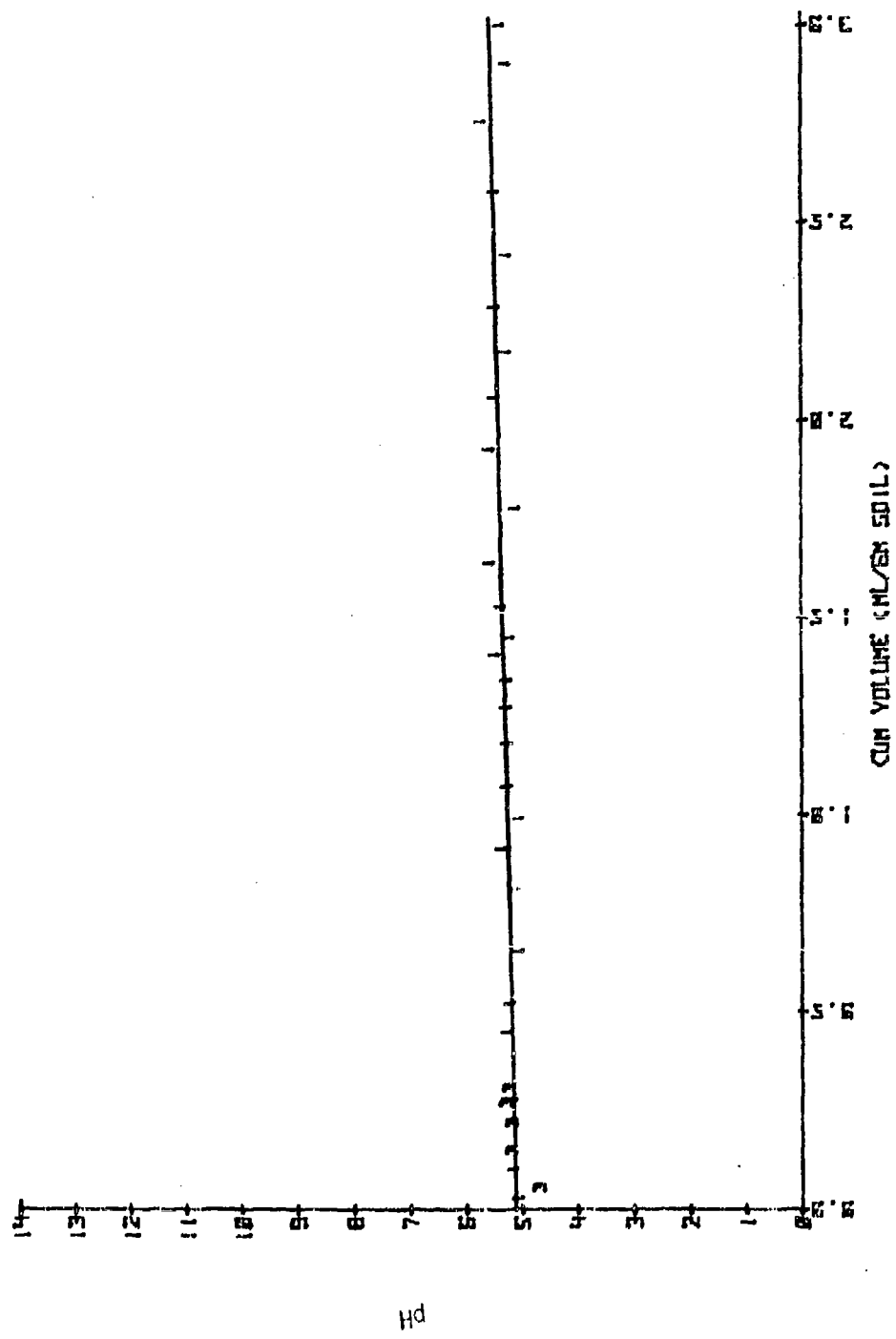


FIGURE 96 : pH OF SOLUTION LEACHED FROM ELECTROPLATING WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

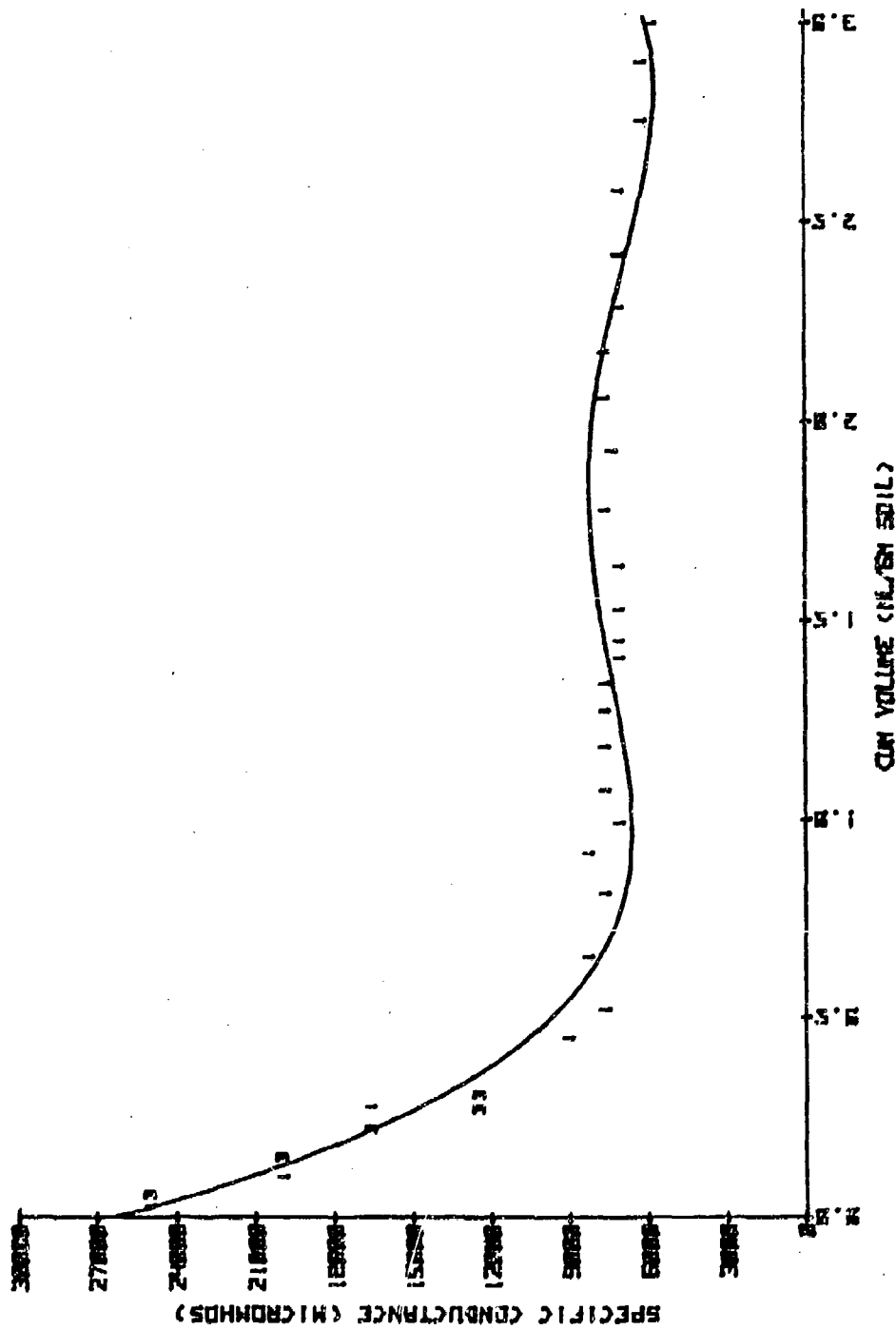


FIGURE 97: CONDUCTANCE OF SOLUTION LEACHED FROM ELECTROPLATING WASTE & KALASKA SOIL BY LANDFILL LEACHATE

Conductance values of the soil column effluents were higher when municipal landfill leachate was used than when water was used as the leaching solution. However, the changes in conductance readings obtained from both solvents were similar, quite high initially but decreasing rapidly as leaching progressed.

Nickel-Cadmium Battery Waste--

Water Extracts--The amounts of cadmium and nickel leached from the nickel-cadmium battery waste by water are shown in Figures 24 and 25 (Section 4). These figures show the variation in metal concentration, with time, in the waste leachate applied to both Davidson and Kalkaska soil columns.

Figures 98 and 99 are plots of cadmium and nickel leached by water from nickel-cadmium battery waste and penetrating Davidson soil. Extremely large quantities of both metals penetrated the soil columns. The drinking water standard was exceeded many thousand times.

Figures 100 and 101 are plots of cadmium and nickel leached by water from nickel-cadmium battery waste and penetrating Kalkaska soil. Both metals penetrated this soil more rapidly than Davidson soil and in greater quantities. The waste challenge was terminated before one pore volume of waste leachate had passed through the soil columns. Even after the waste was removed and the water leach started, the drinking standard was exceeded several hundred times throughout the period of water leaching. This was true for Davidson soil, also.

Figure 102 shows the fraction of the input of each metal, from the water leaching of the nickel-cadmium battery waste, that passes through each soil.

The results in Figure 102 show that Davidson soil is much more effective in removing both metals from the waste leachate than is Kalkaska soil. The Davidson soil proved to be very effective in removing nickel from the waste leachate even though the amount applied to the soil column (in the waste leachate) was extremely high.

Landfill Leachate Extract--The amounts of cadmium and nickel leached from the nickel-cadmium battery waste by municipal landfill leachate are shown in Figures 28 and 29 (Section 4). Figures 103 and 104 are plots of cadmium and nickel leached by municipal landfill leachate from nickel-cadmium battery waste and penetrating Davidson soil. Cadmium leached in high concentrations. The initial sample was low but still far in excess of the drinking water standard. The concentration of cadmium increased rapidly to extremely high levels after a cumulative volume of 0.25 milliliter/gram soil (approximately 40 milliliters).

2.8- X 10³

1.8-

1.6-

1.4-

1.2-

1.0-

0.8-

0.6-

0.4-

0.2-

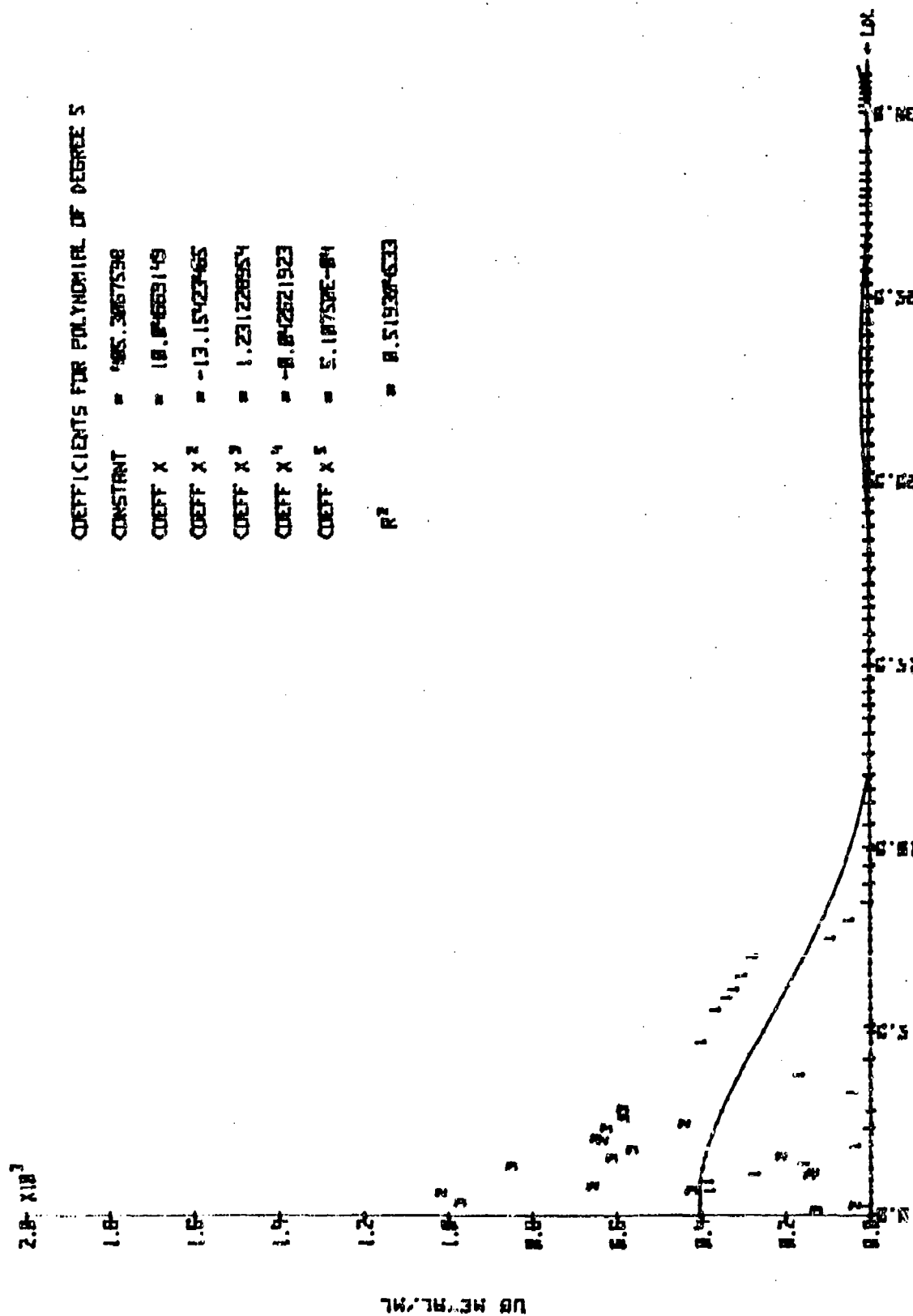
0.0-

UR RECALCULATED

176

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 485.3867598
 COEFF X = 18.84653149
 COEFF X² = -13.15427465
 COEFF X³ = 1.231228554
 COEFF X⁴ = -8.842621923
 COEFF X⁵ = 5.187585-84
 R² = 0.519387633



CUM VOLUME (ML/50 ML SOIL)

FIGURE 98: CADMIUM LERCHED FROM NI-CO BATTERY WASTE & DAVIDSON SOIL BY WATER

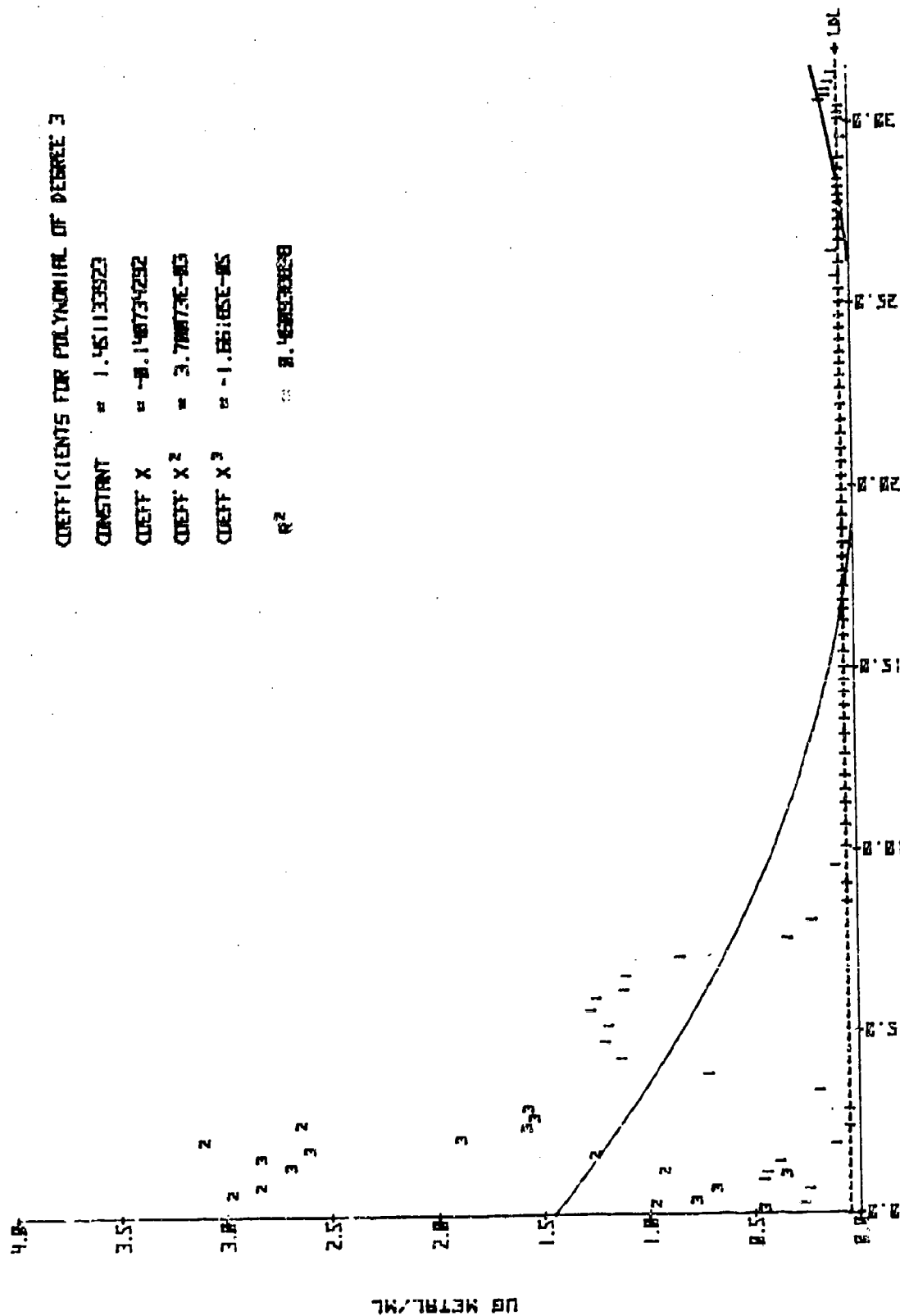
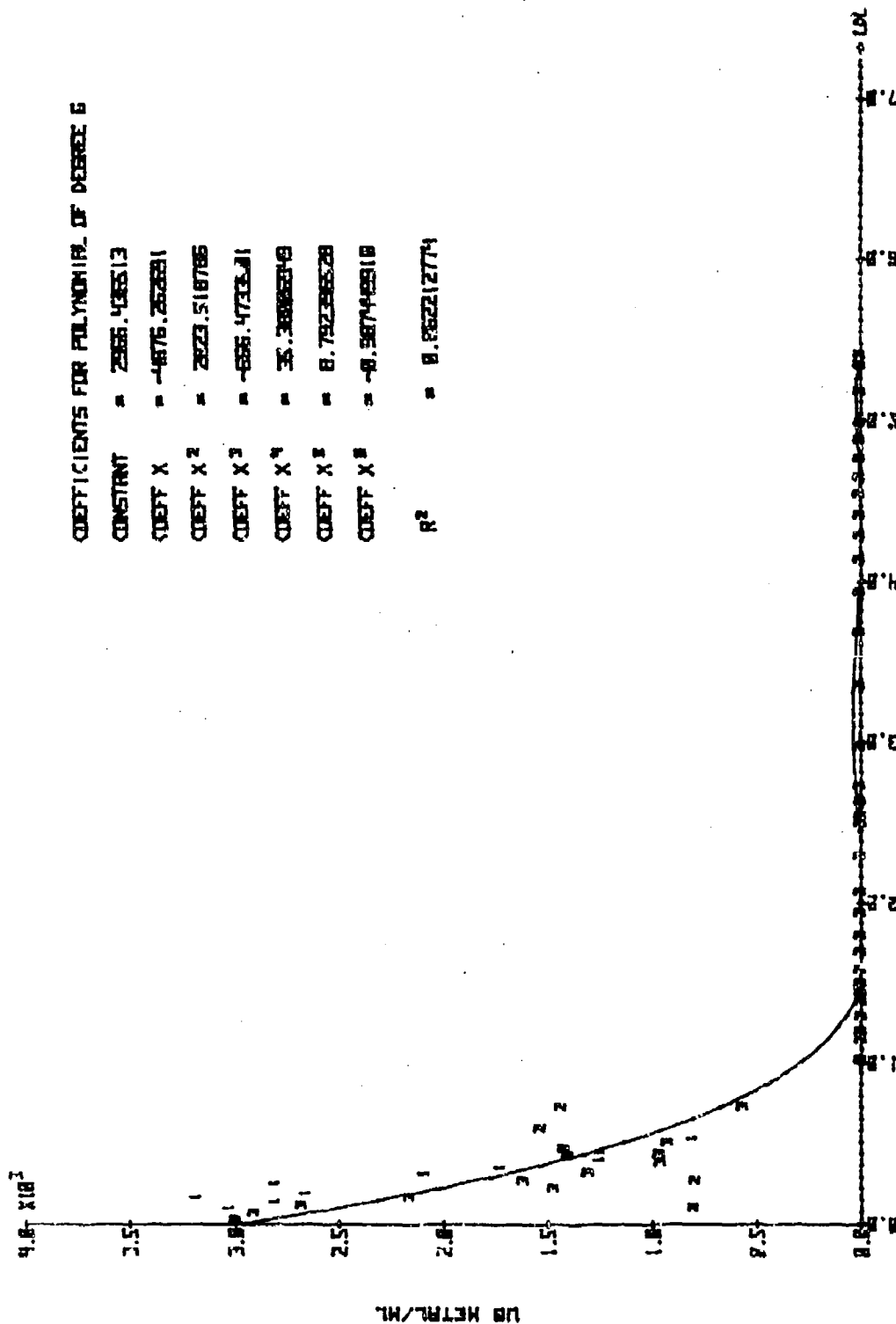


FIGURE 99: NICKEL LEACHED FROM NI-CD BATTERY WASTE & DAVIDSON SOIL BY WATER

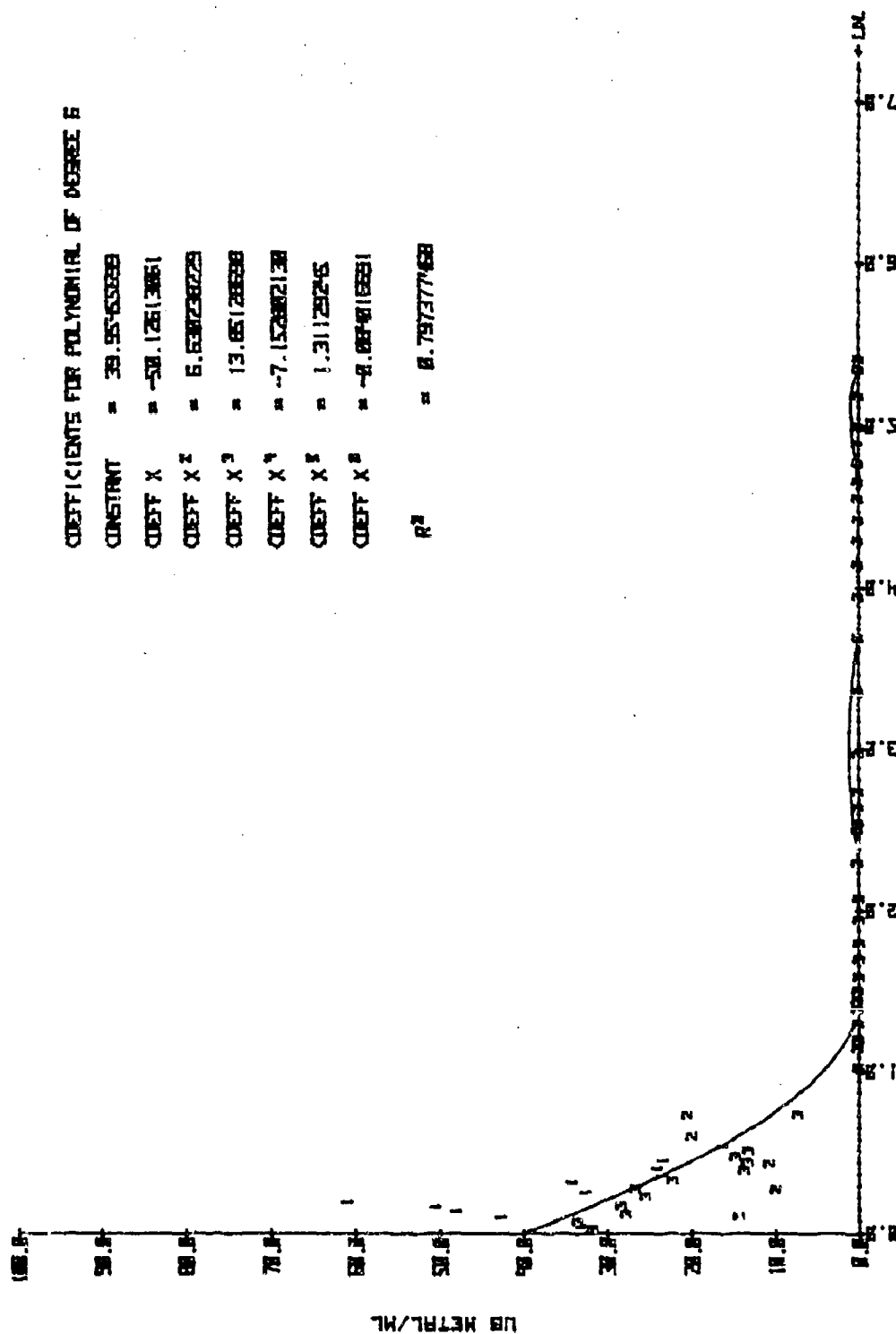


COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT	= 2555.435513
COEFF X	= -4876.252331
COEFF X ²	= 2623.518785
COEFF X ³	= -555.477331
COEFF X ⁴	= 35.3886249
COEFF X ⁵	= 0.79238528
COEFF X ⁶	= -0.58749318
R ²	= 0.852212774

Cd CONCENTRATION (ug METAL/ML)

FIGURE 130 : CADMIUM LEACHED FROM NI-CD BATTERY WASTE & KALKASKA SOIL BY WATER



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 39.9556388

COEFF X = -58.12613661

COEFF X² = 6.630238229

COEFF X³ = 13.65128888

COEFF X⁴ = -7.152882138

COEFF X⁵ = 1.31129245

COEFF X⁶ = -8.884818881

R² = 0.7977768

CUV VOLUME (ML/GN SOIL)

FIGURE 101: NICKEL LEACHED FROM Ni-CD BATTERY WASTE & KALKASKA SOIL BY WATER

D= DAVIDSON

K= KALKASKA

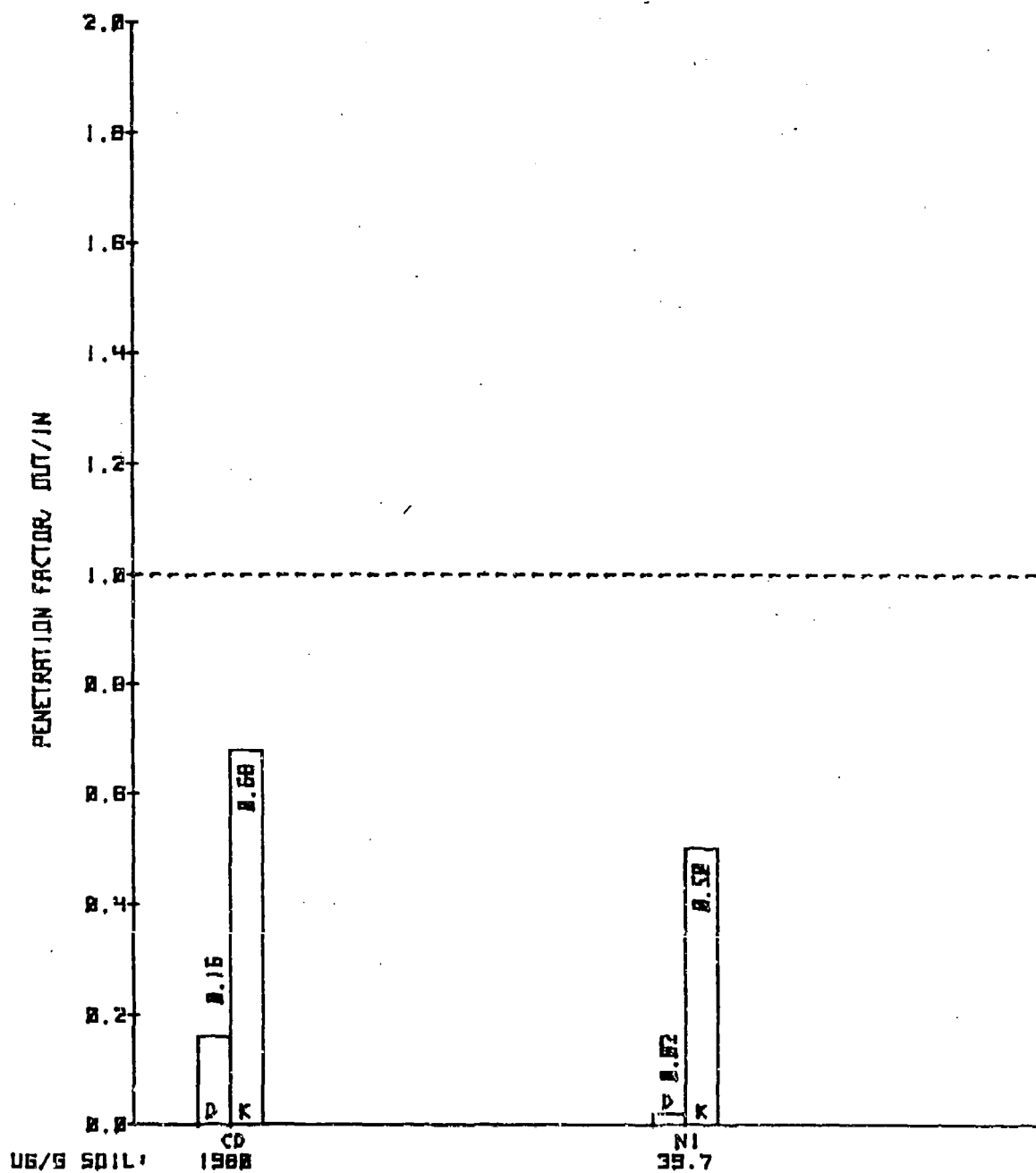


FIGURE 102: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A WATER EXTRACT OF NI-CO BATTERY WASTE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 75.78781525
 COEFF X = -3874.887905
 COEFF X² = 19817.28193
 COEFF X³ = -21388.87455
 COEFF X⁴ = 8853.827866
 COEFF X⁵ = -1279.134388
 R² = 0.854863889

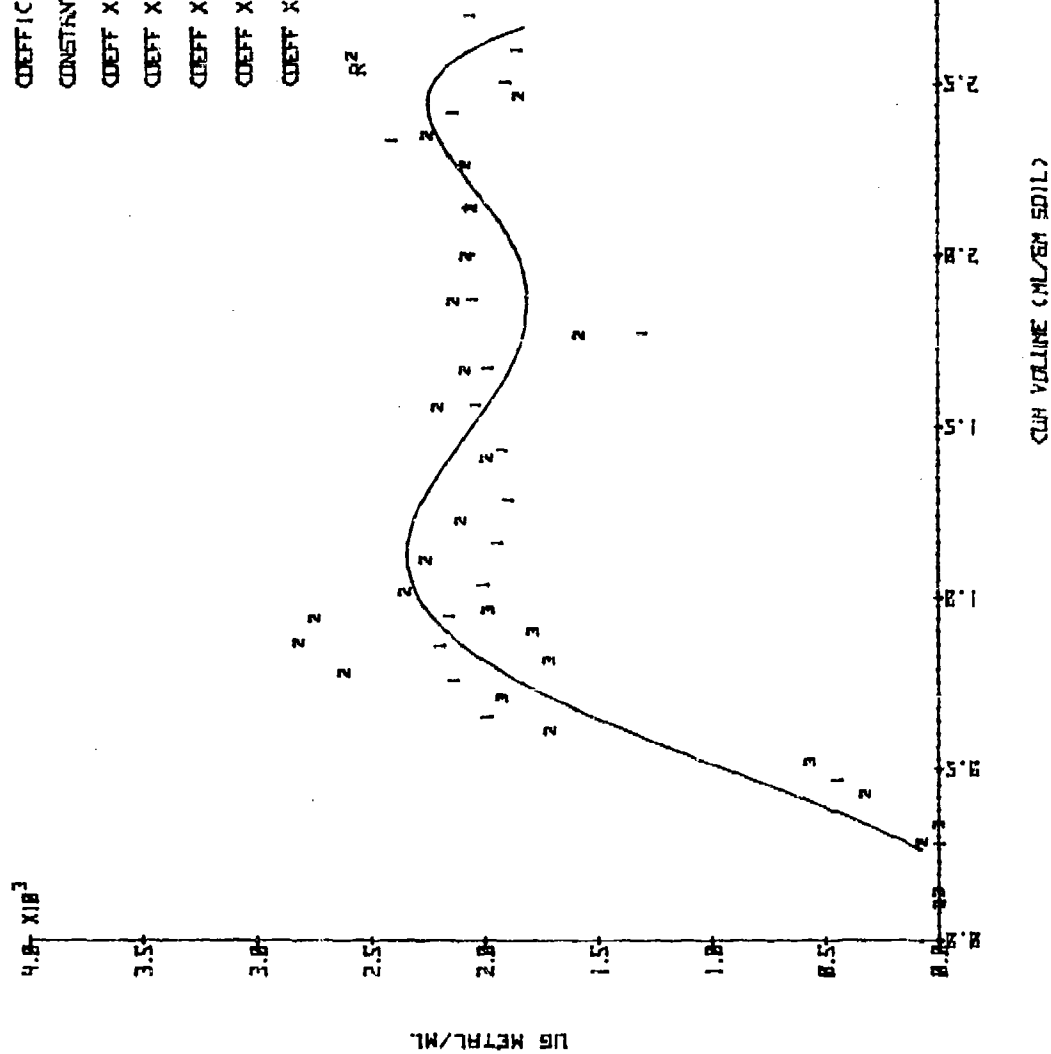
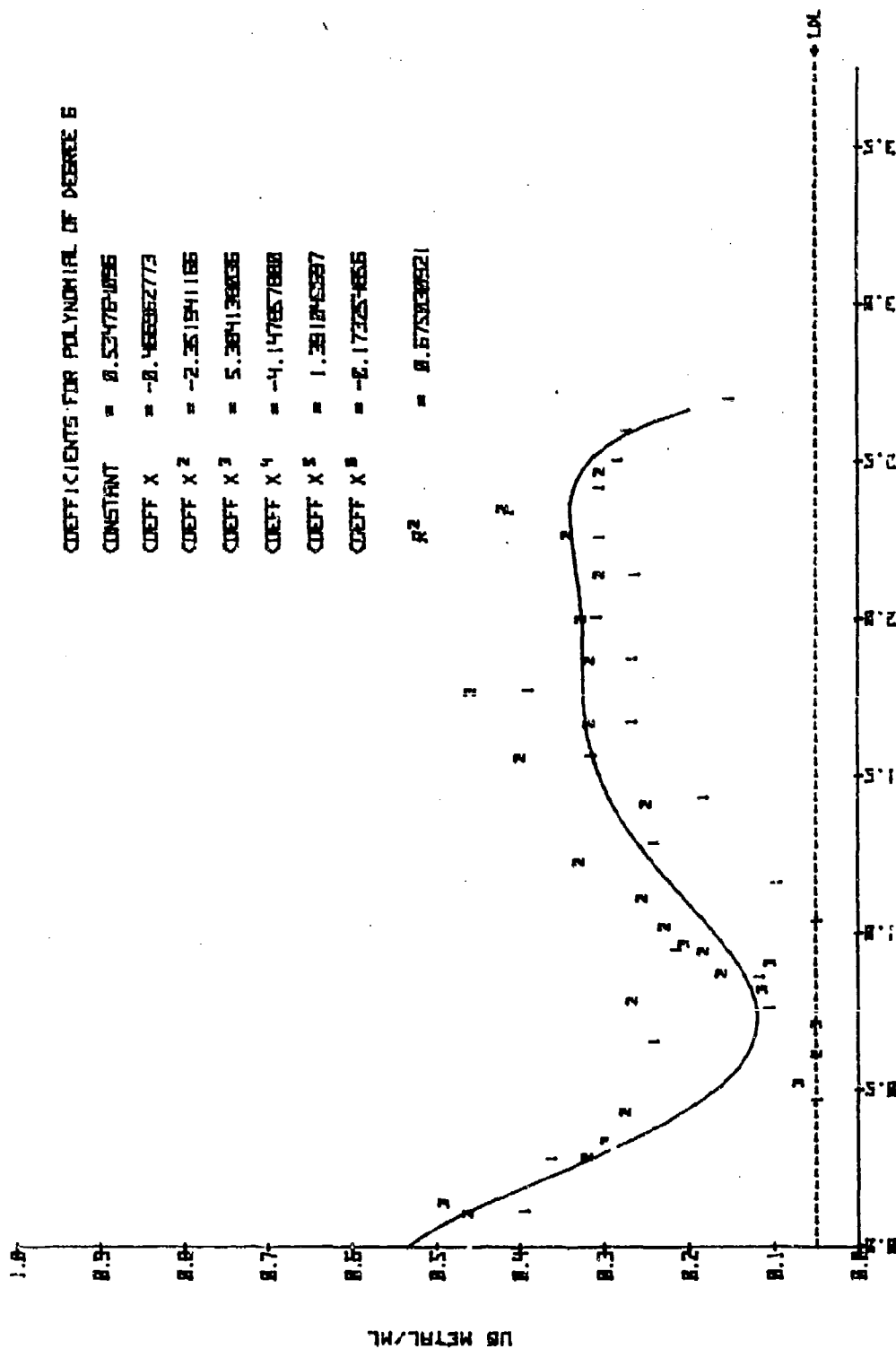


FIGURE 103: CHROMIUM LEACHED FROM NI-CD BATTERY WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



CUM VOLUME (ML/GH SOIL)

FIGURE 104: NICKEL LEACHED FROM NI-CD BATTERY WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

Nickel leached through the soil at levels lower than was found when water was used to leach the waste. The reason for this behavior is not understood at present.

Figures 105 and 106 are plots of cadmium and nickel leached by municipal landfill leachate from nickel-cadmium battery waste and penetrating Kalkaska soil. Cadmium passed through this soil in extremely high concentrations throughout the leaching period. The nickel passed through the soil at much lower levels than the cadmium and at a level lower than found when water was used to leach the waste.

Figure 107 shows the fraction of the input of each metal, from the municipal landfill leachate leaching of the nickel-cadmium battery waste, that passes through each soil.

As was mentioned previously in the electroplating waste section, it would appear that a smaller problem would occur if municipal landfill leachate is used as the leaching solvent if compared to the water factors. It must be remembered that the soil columns were leached by municipal landfill leachate for a very short period as compared to water. Therefore, the penetration factors are useful only in comparing soil-waste columns leached by the same solvent.

pH and Conductance Measurements--Figures 108 through 115 are plots of the pH and specific conductance values of the soil column effluent samples from both soils and both leaching solvents. The pH values seem low when compared with the pH of water and the landfill leachate extracts of the waste. See Figures 26 and 30 in Section 4. These low pH values in the soil column effluents are a reflection of the strong buffering capacity of soils, even when challenged by high strength solutions such as these. The pH of effluents from the Kalkaska soil (Figures 110 and 114) are always lower than the pH of the corresponding effluent from the Davidson soil (Figures 108 and 112), reflecting initial pH differences between the soils. The conductance value provided additional information as to the high solubility of the waste leachates and their effect upon both soils. The initial conductance values were extremely high and then dropped off. However, the later values were still quite high. In both of the waste leachates applied to the soil columns and in the soil column effluents, the specific conductance values were higher when municipal landfill leachate was used. This reflects the greater amount of metals solubilized and a more rapid movement through the soil.

Inorganic Pigment Waste--

Water Extracts--The amounts of cadmium, chromium, copper, nickel, lead, and zinc leached from the inorganic pigment waste by water are shown in Figures 32 through 37 (Section 4). These Figures show the variation in metal concentration with time, in the waste leachate applied to both Davidson and Kalkaska soil columns.

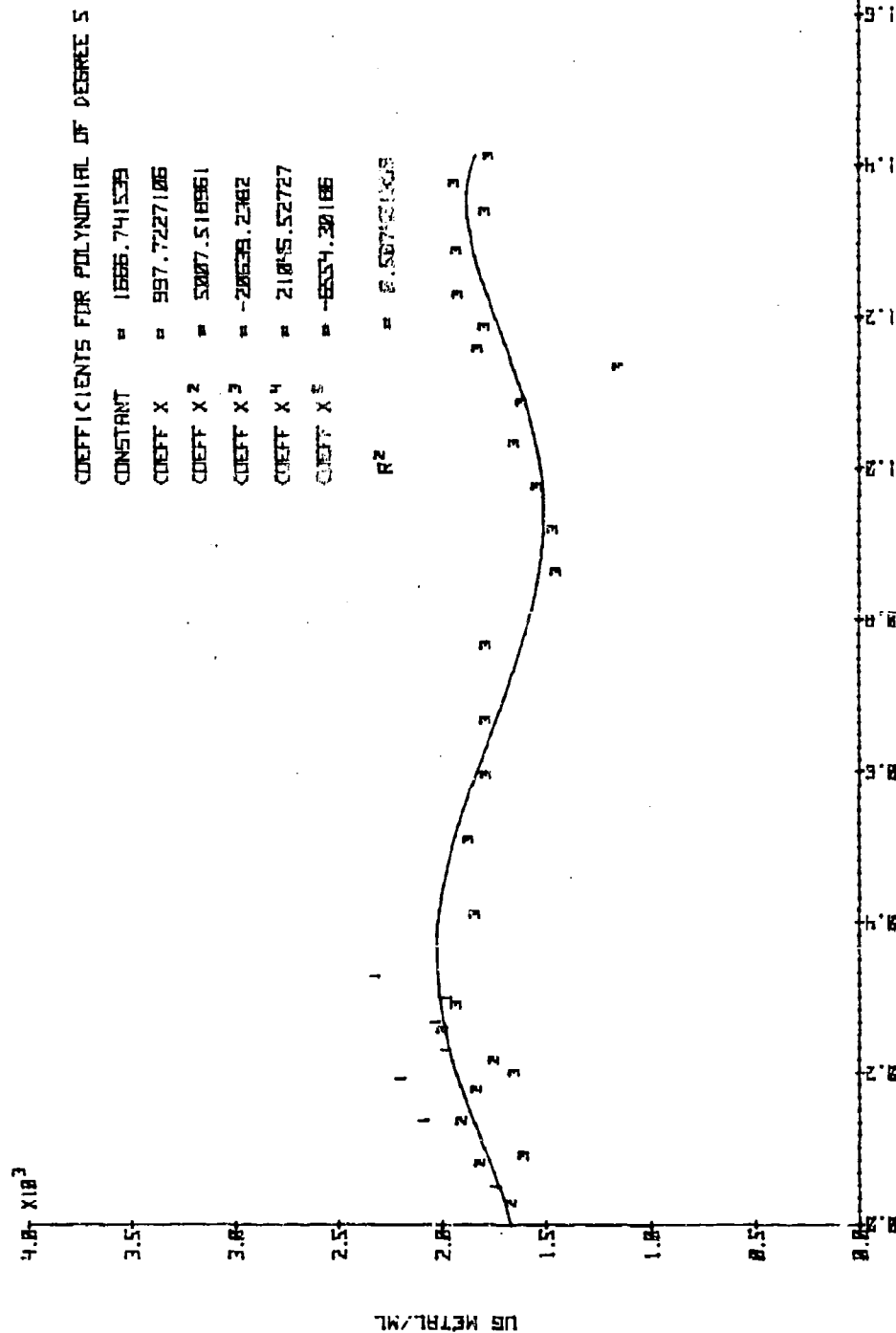


FIGURE 105: CADMIUM LEACHED FROM NI-CO BATTERY WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

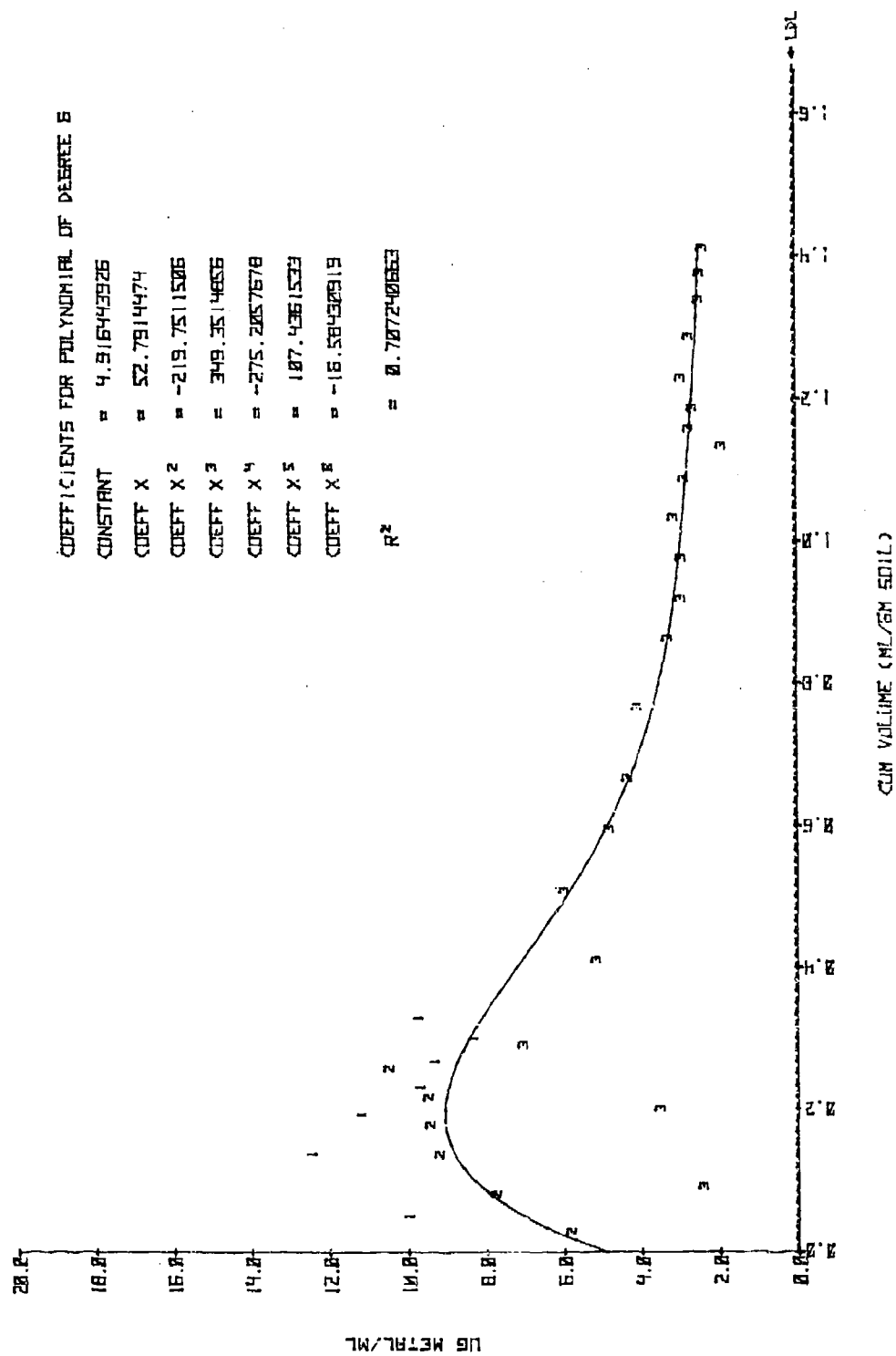


FIGURE 106: NICKEL LERCHED FROM NI-CD BATTERY WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

D= DAVIDSON

K= KALKASKA

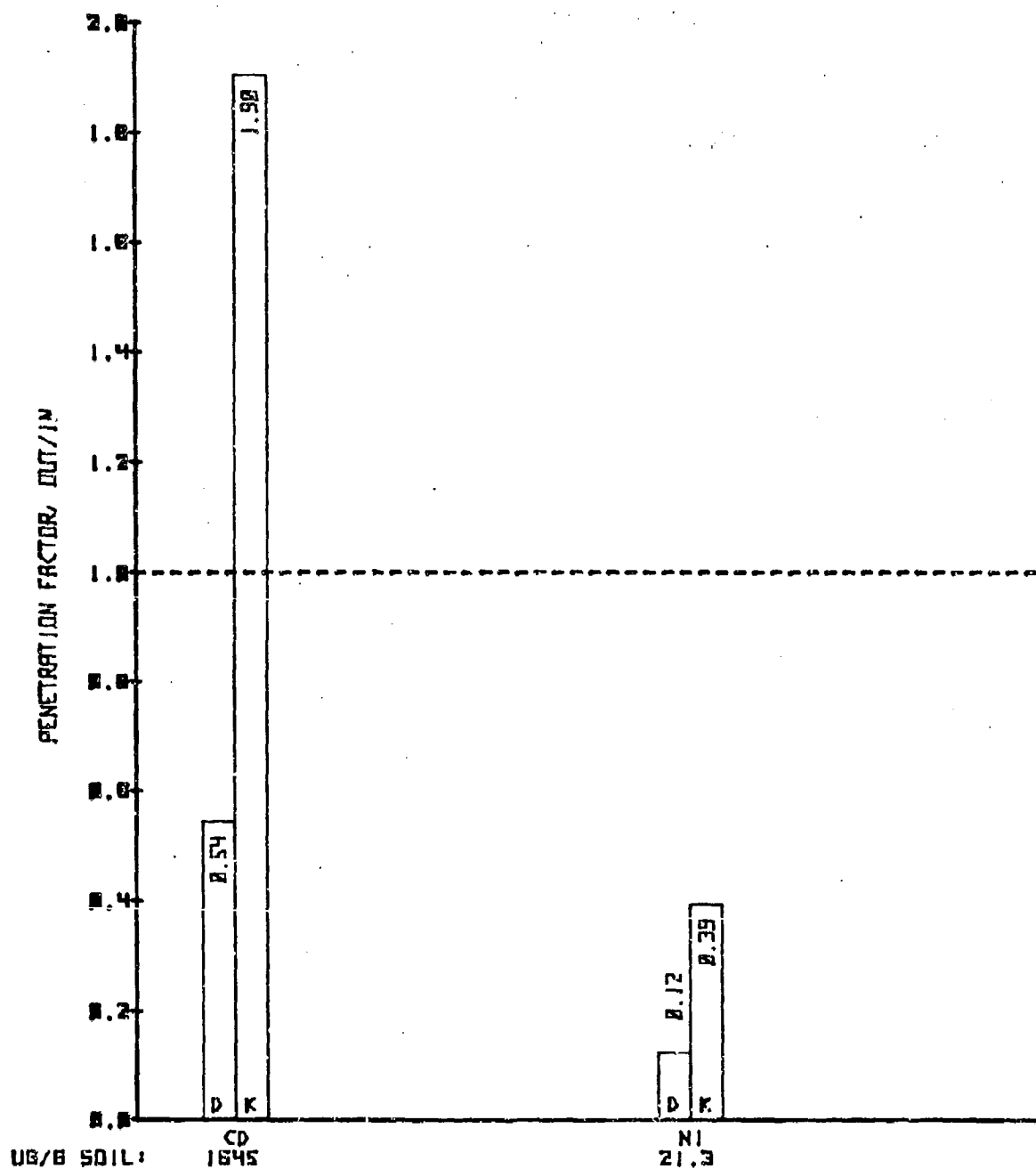


FIGURE 107: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A LANDFILL LEACHATE EXTRACT OF NI-CD BATTERY WASTE

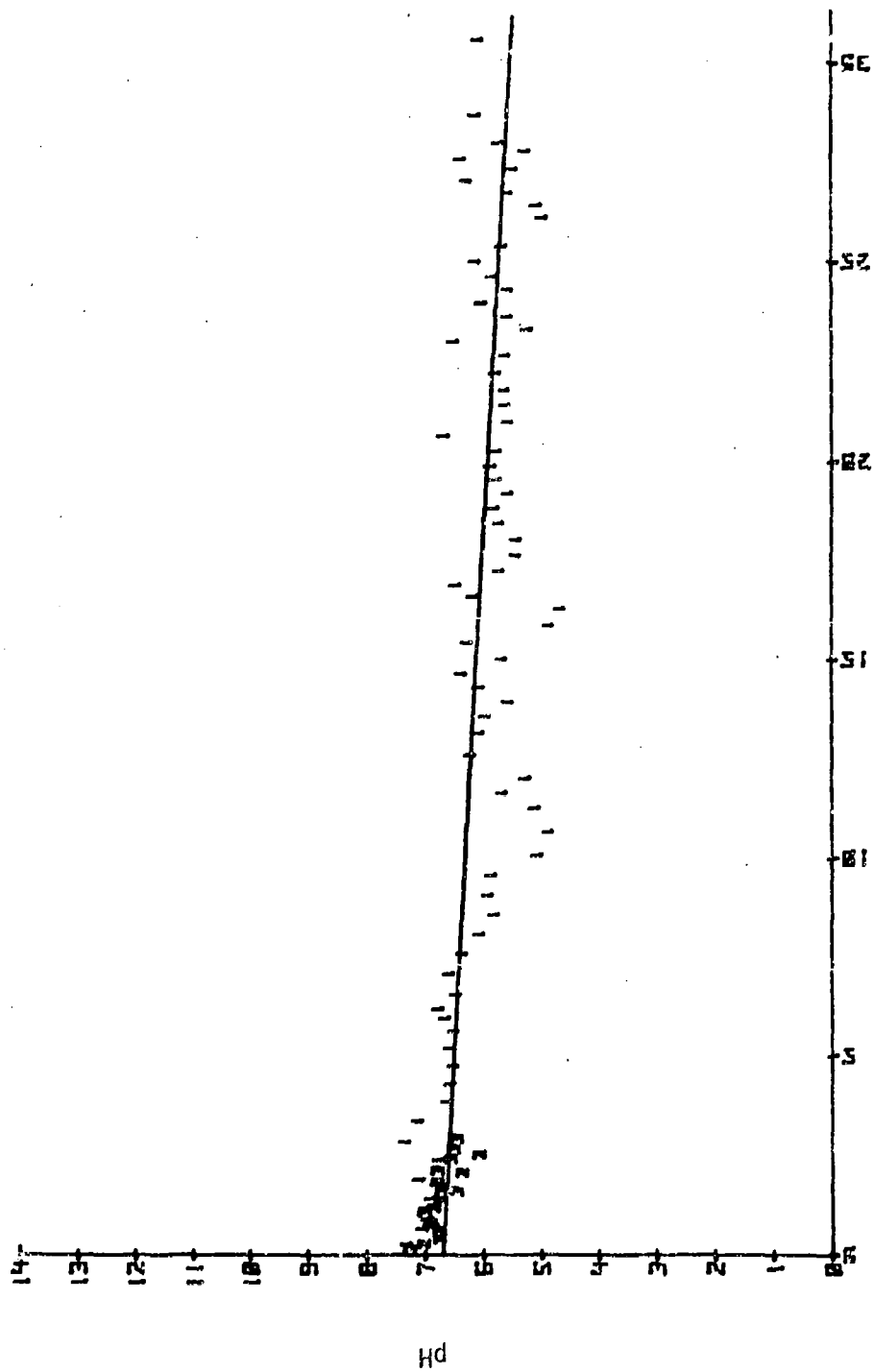


FIGURE 108 : pH OF SOLUTION LEACHED FROM NI-CD BATTERY
WASTE & DAVIDSON SOIL BY WATER

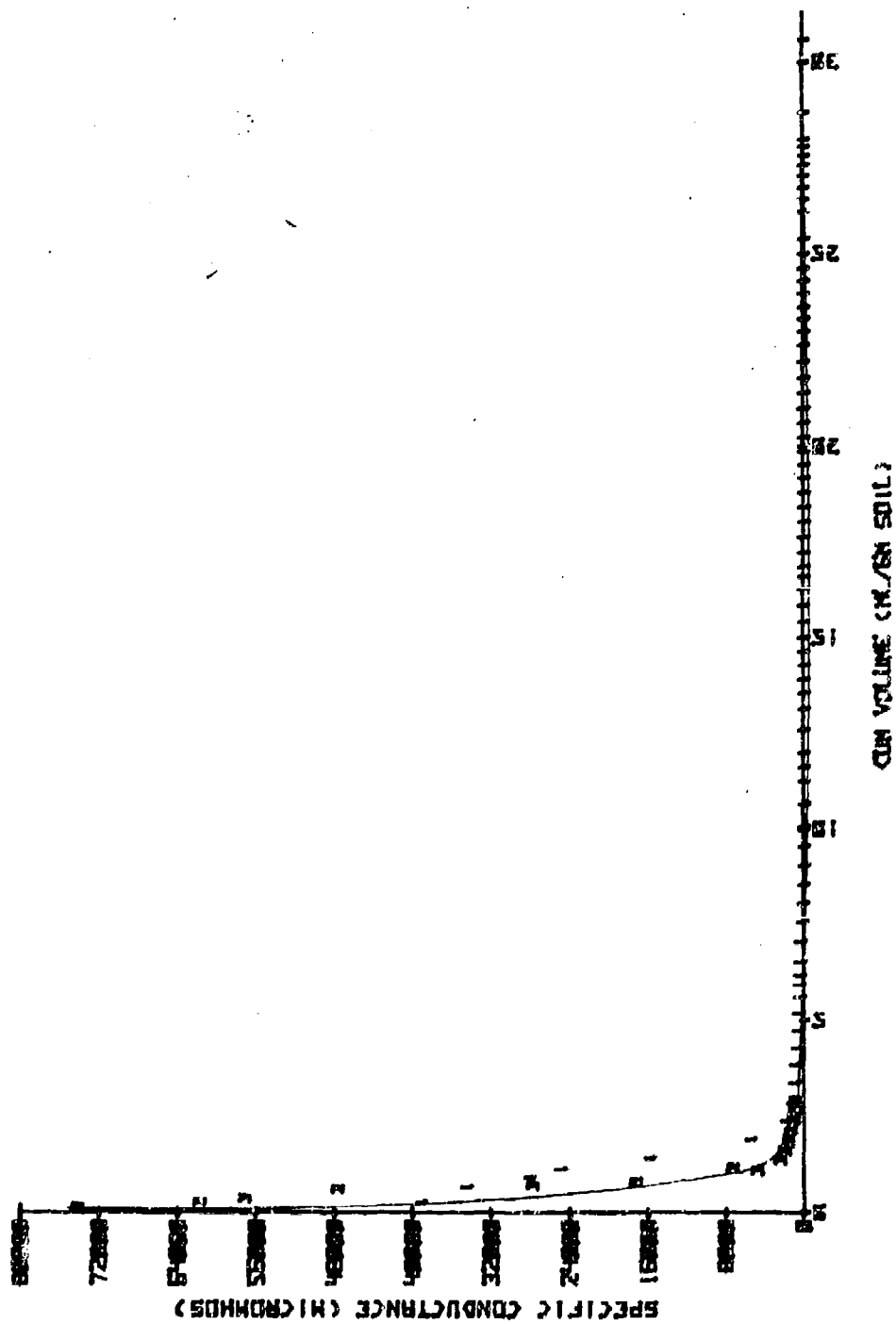


FIGURE 109: CONDUCTANCE OF SOLUTION LEACHED FROM NI-CO BATTERY
WASTE & DAVIDSON SOIL BY WATER

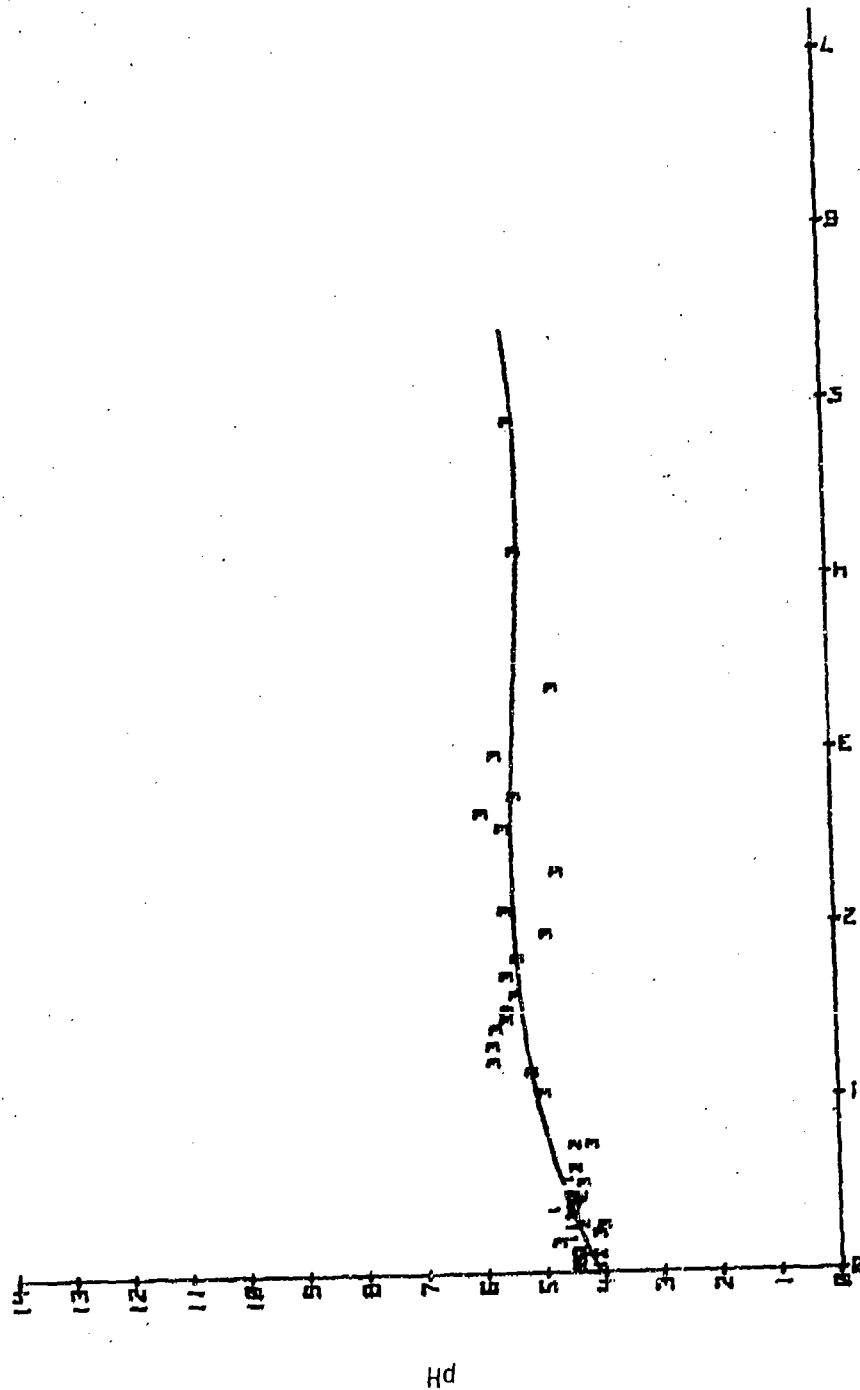


FIGURE 110: pH OF SOLUTION LEACHED FROM NI-CD BATTERY
WASTE & KALKASKA SOIL BY WATER
CUM VOLUME (ML/GN SOIL)

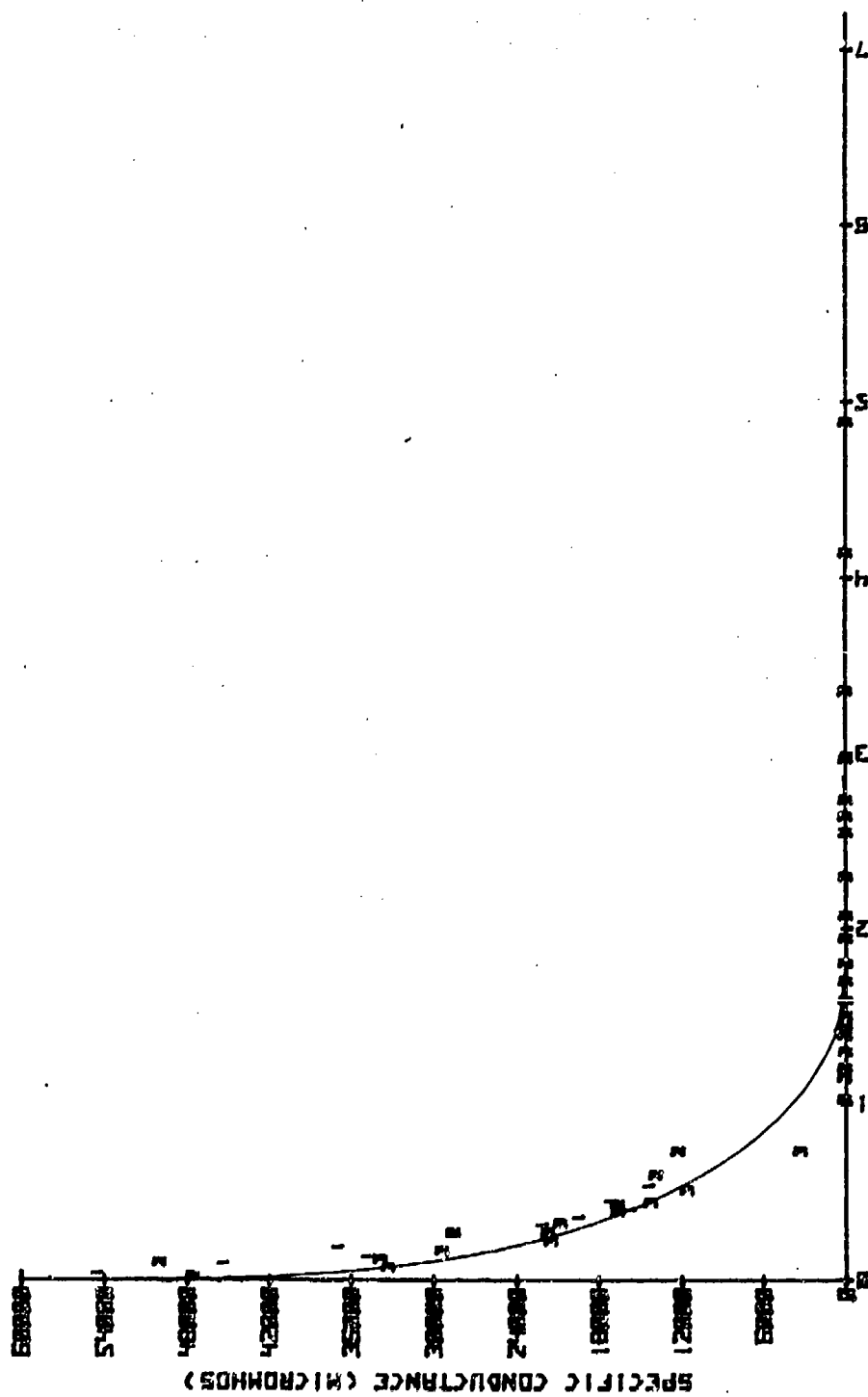


FIGURE 111 : CONDUCTANCE OF SOLUTION LEACHED FROM NI-CD BATTERY
WASTE & KALKASKA SOIL BY WATER

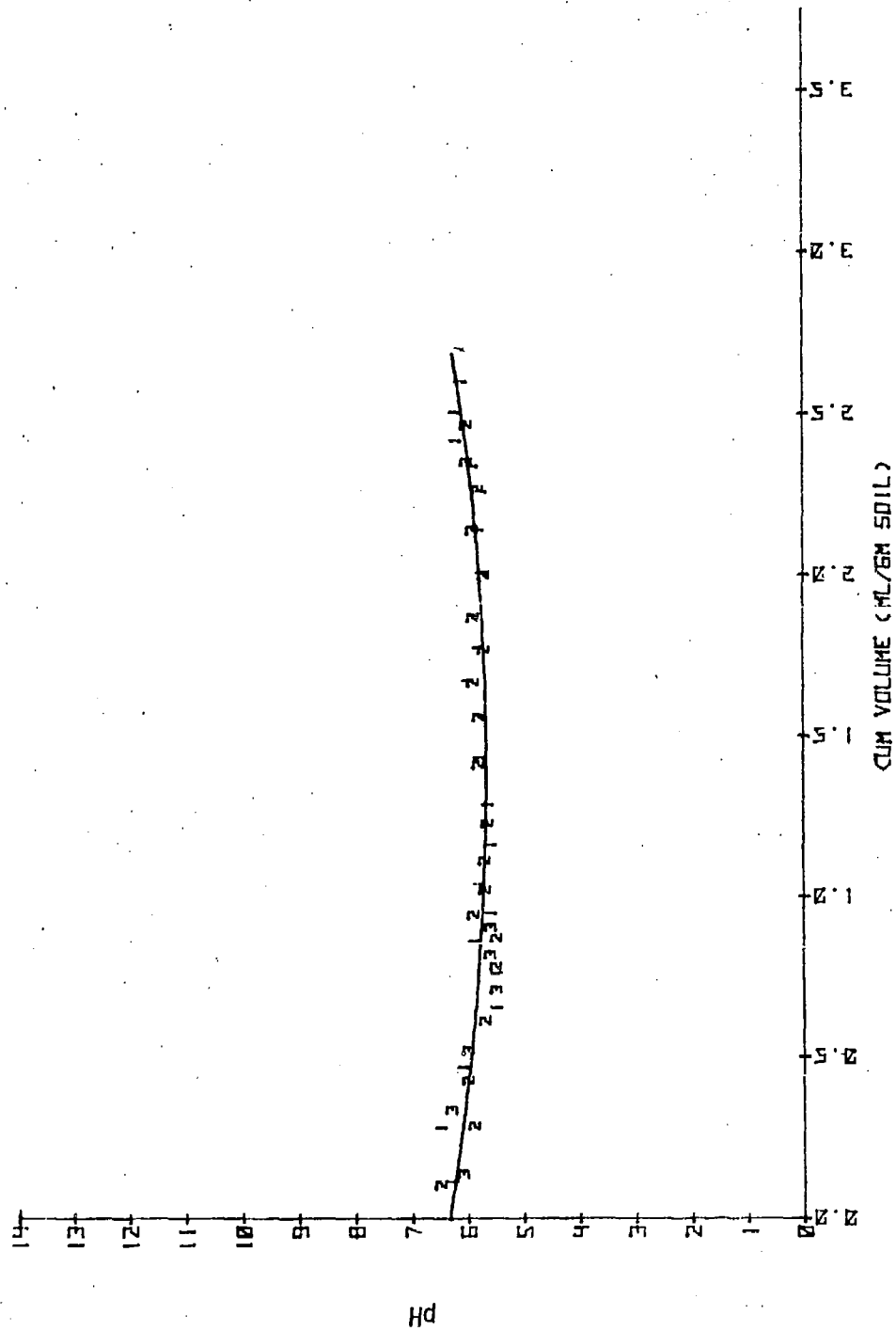


FIGURE 112: pH OF SOLUTION LEACHED FROM NI-CD BATTERY WASTE & DRAINAGE SOIL BY LANDFILL LEACHATE

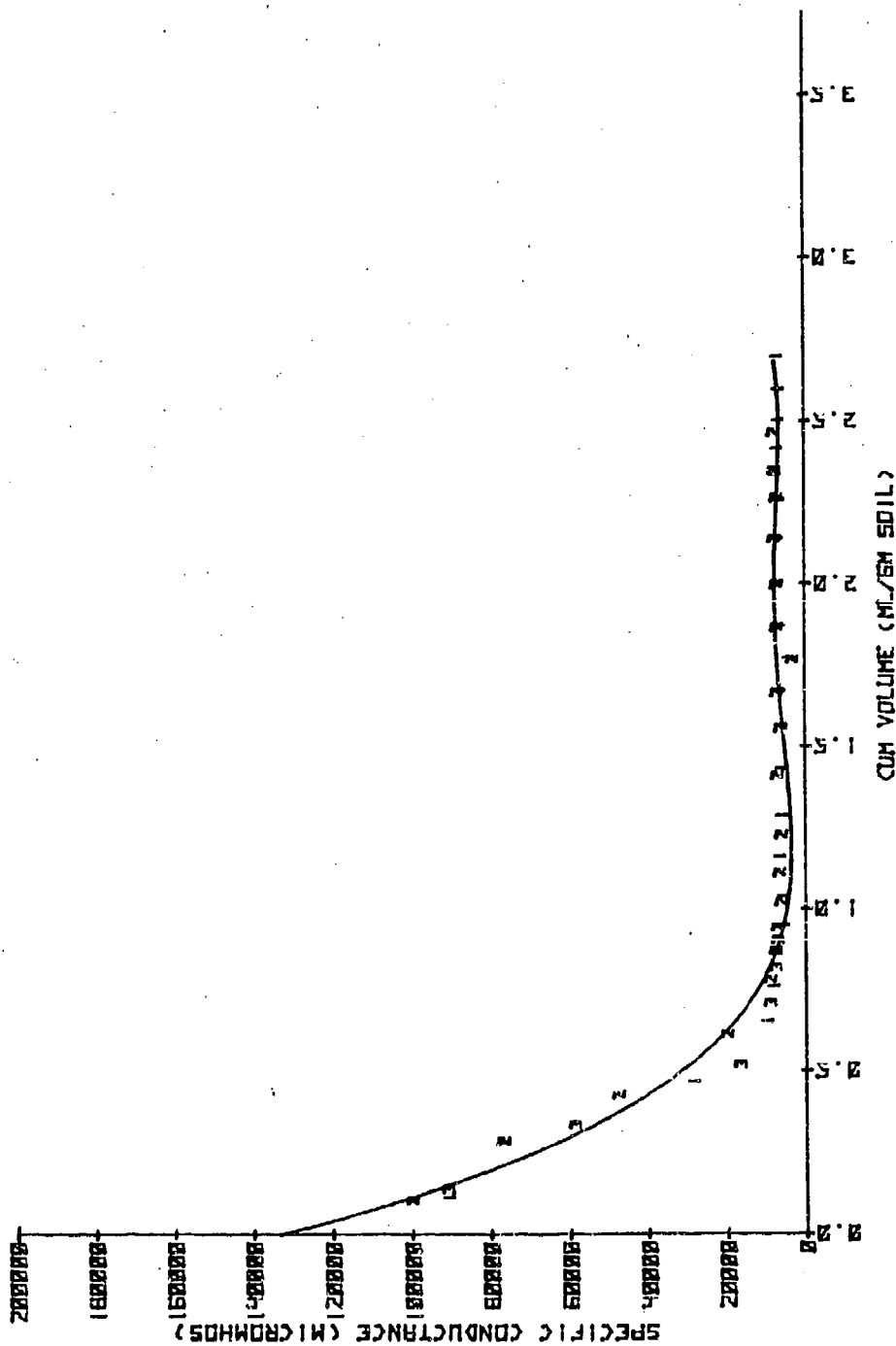


FIGURE 113: CONDUCTANCE OF SOLUTION LEACHED FROM NI-CD BATTERY
WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

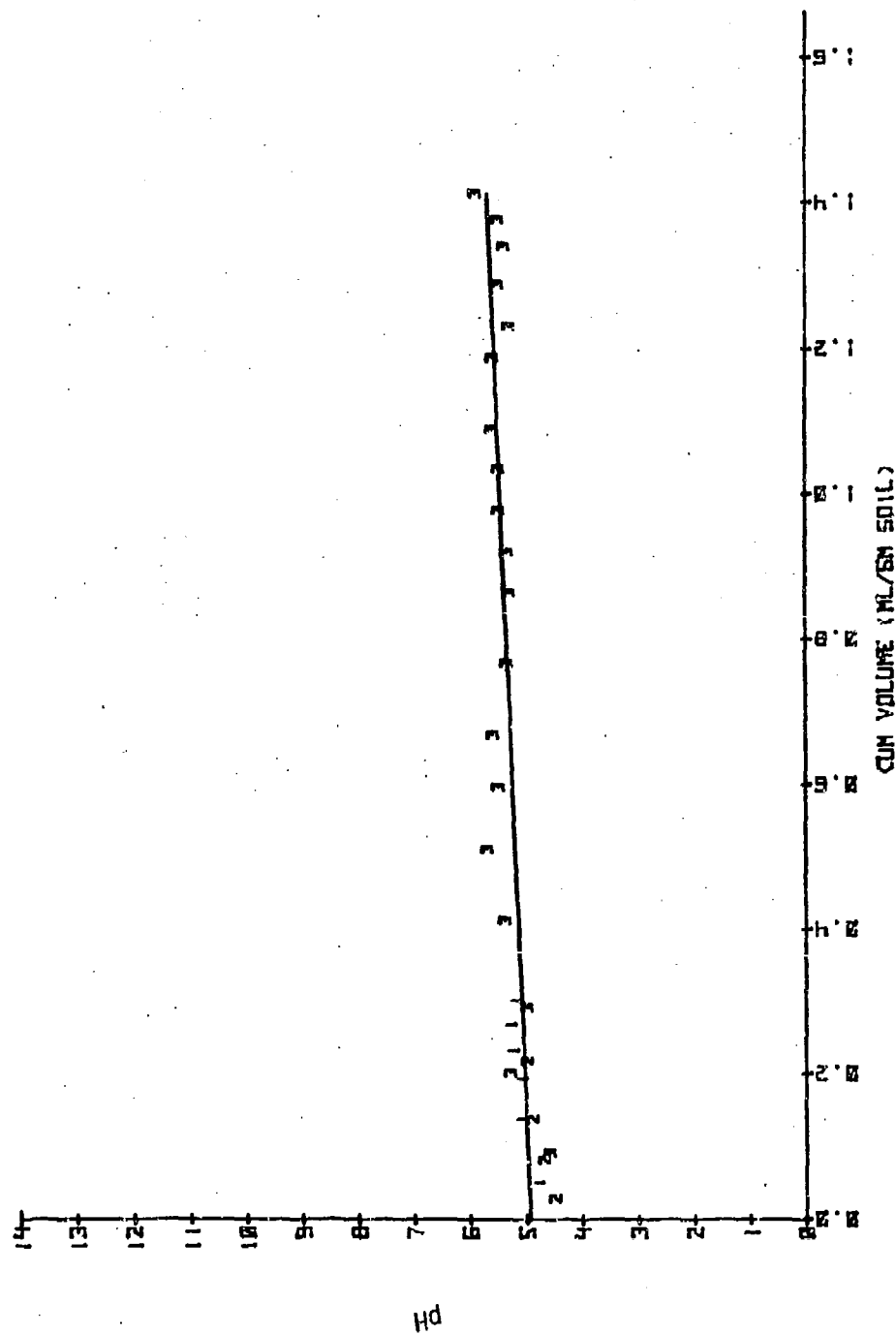


FIGURE 114: pH OF SOLUTION LEACHED FROM NI-CD BATTERY WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

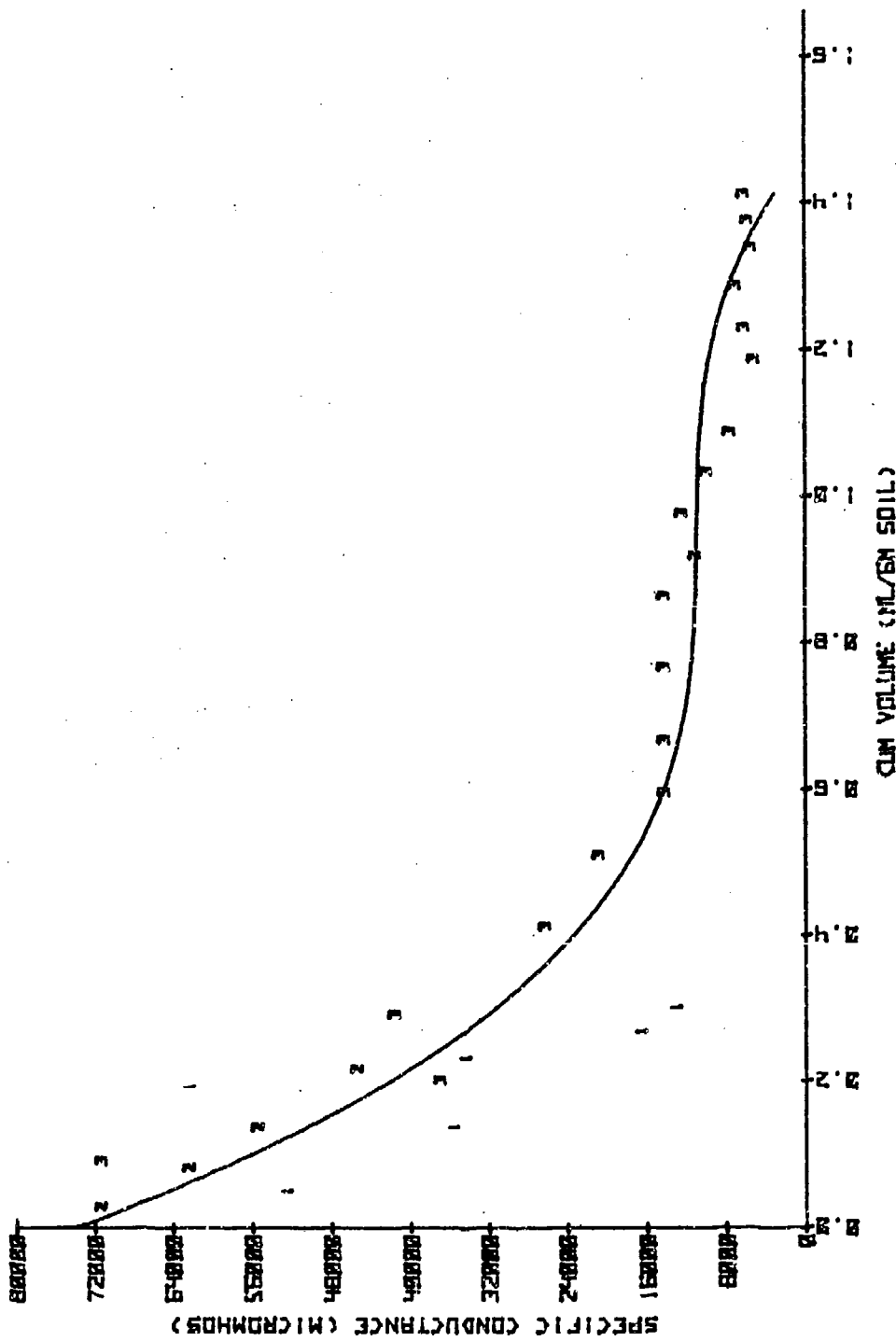


FIGURE 115: CONDUCTANCE OF SOLUTION LEACHED FROM NI-CD BATTERY WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

Figures 116 through 120 are plots of cadmium, chromium, copper, nickel, and zinc leached by water from inorganic pigment waste and penetrating Davidson soil. Cadmium was found present during the first part of the leaching period up to approximately 10 milliliters/gram soil. Thereafter, except for an occasional sample, it was not detected in the soil column effluent. Chromium was not found in the samples until a very large volume of waste leachate had passed through the soil column (3,360 milliliters or 84 pore volumes). The copper data were plotted, but the results were very scattered, so no regression equation was fitted. The concentration of copper in the individual samples never exceeded the drinking water standard. Neither nickel nor zinc exceeded the standards.

Figures 121 through 125 are plots of cadmium, chromium, copper, nickel, and zinc leached by water from inorganic pigment waste and penetrating Kalkaska soil. Cadmium and chromium exceeded the drinking water standard by a greater margin and earlier in the leaching period than for the Davidson soil. The chromium results were scattered, so a regression equation could not be accurately derived. Chromium was present sporadically at concentrations in excess of the standard, particularly during the latter part of the leaching period. Copper was likewise detected sporadically in the soil column effluents but never above drinking water levels. Nickel and zinc were found continuously in substantial concentrations but did not exceed the standard.

Figure 126 shows the fraction of the input of each metal, from the water leaching of the inorganic pigment waste, that passes through each soil.

Most of the metals were found in the waste leachate samples in low concentrations. This causes some imprecision in deriving a regression equation that could be used to calculate the challenge concentration applied to the soil columns. This is reflected in the soil column data and is further complicated by the apparent leaching of some metals naturally present in both soils by the waste leachate. Although the concentrations of the metal, naturally present in the soils and leached by the waste leachate, may be very low it becomes significant if the challenge concentration is also very low.

Landfill Leachate Extracts--The amounts of cadmium, chromium, copper, lead, nickel, and zinc leached from the inorganic pigment waste by municipal landfill leachate are shown in Figures 40 through 45 (Section 4). Figures 127 through 132 are plots of cadmium, copper, lead, mercury, nickel, and zinc leached by municipal landfill leachate from inorganic pigment waste and penetrating Davidson soil. Cadmium penetrated the soil in high concentrations initially and then decreased rapidly to a much lower level. Lead also exceeded the drinking water level. Mercury was detected also in these samples. A small amount was from the waste, but it is likely some is from the municipal landfill leachate and the soil.

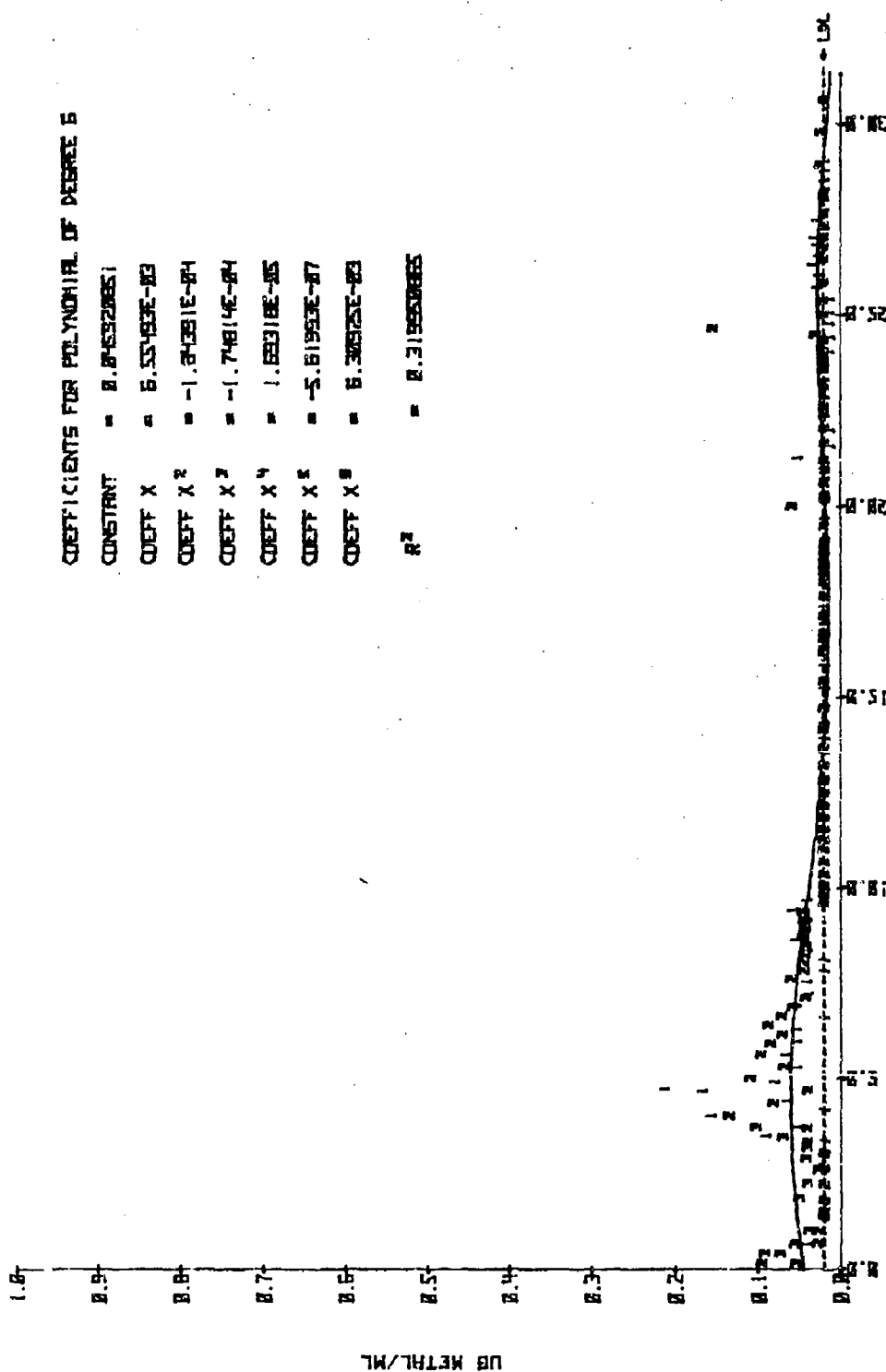
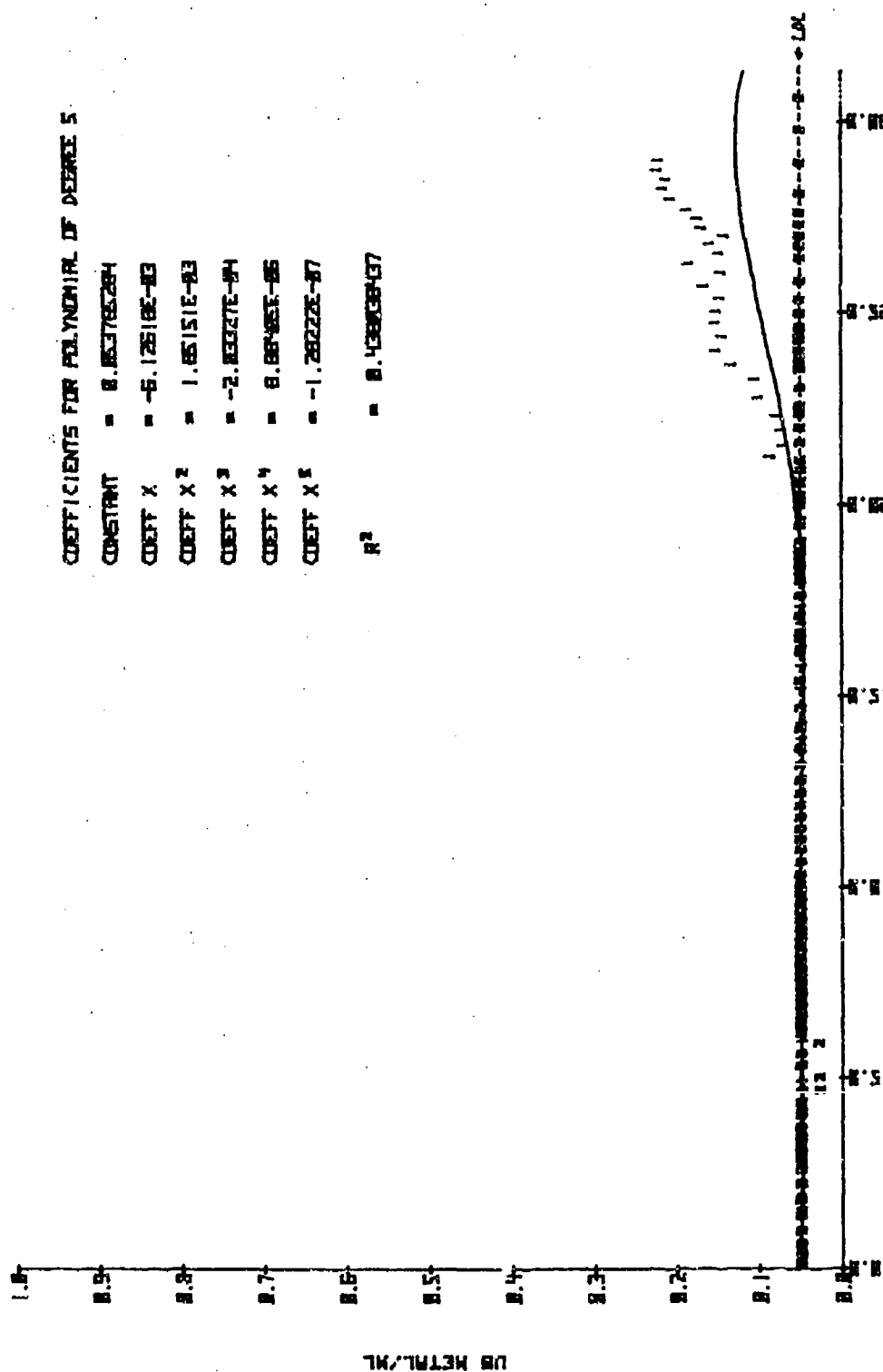


FIGURE 116: CADMIUM LEACHED FROM PISMENT WASTE & DAVIDSON SOIL BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.045320851
 COEFF X = 0.554530E-03
 COEFF X² = -1.24381E-04
 COEFF X³ = -1.74814E-04
 COEFF X⁴ = 1.69318E-05
 COEFF X⁵ = -5.61953E-07
 COEFF X⁶ = 6.30575E-03
 R² = 0.319550865



CUM VOLUME (ML/GR SOIL)

FIGURE 117: CHROMIUM LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY WATER

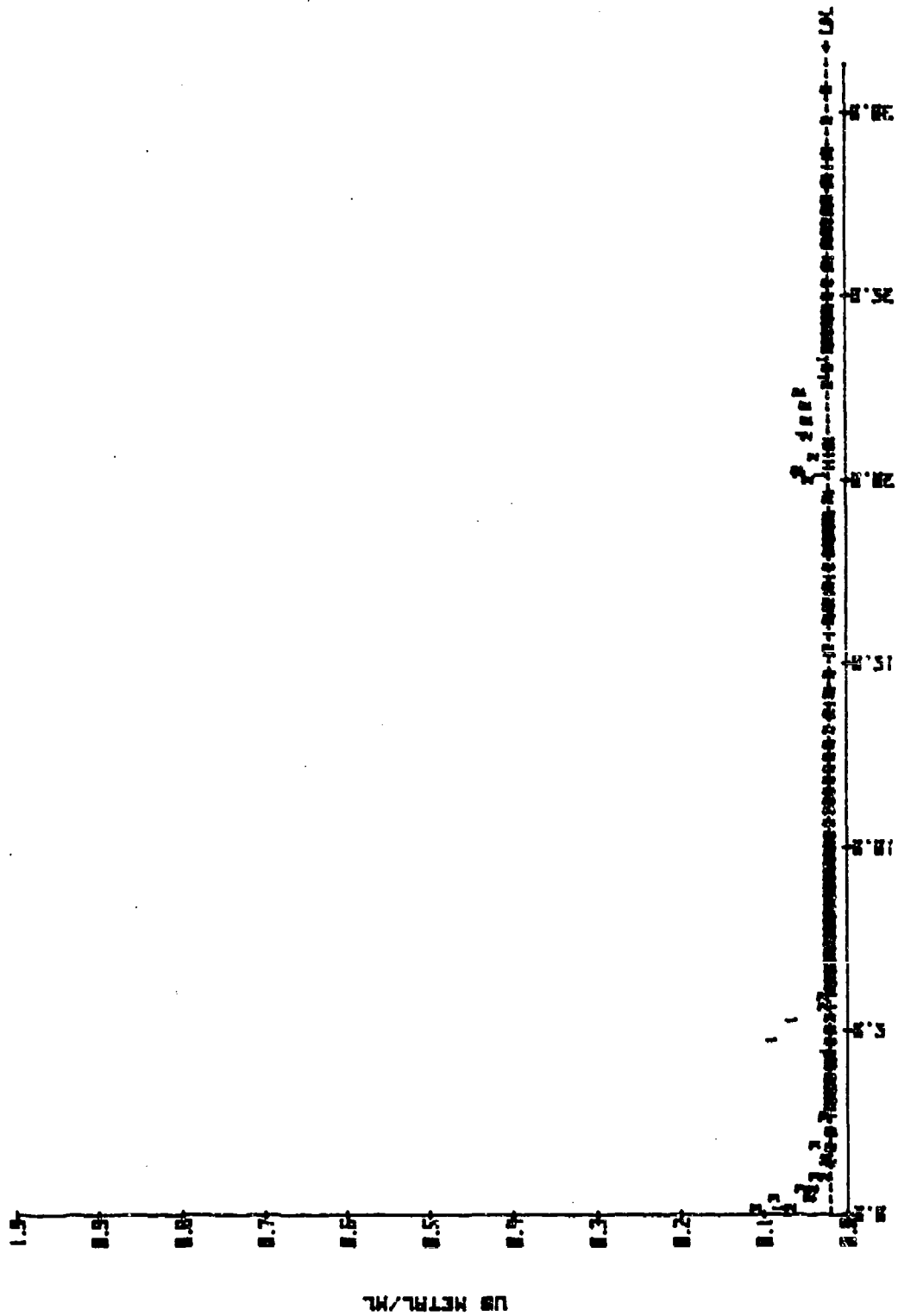
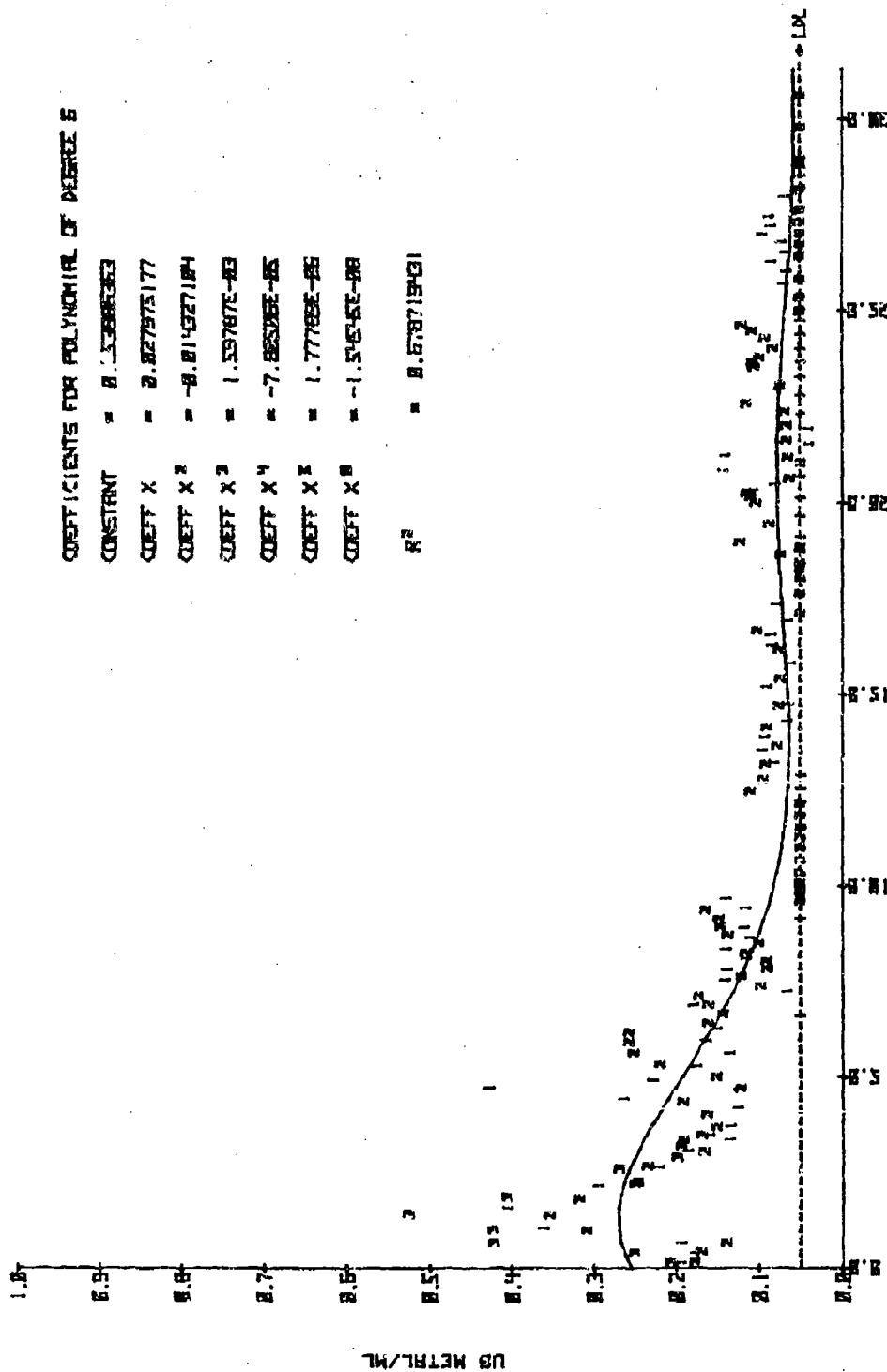


FIGURE 118: COPPER LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY WATER



CLM VOLUME (ML/BA SOIL)

FIGURE 119 : NICKEL LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.53886363

COEFF X = 0.027975177

COEFF X² = -0.014927184

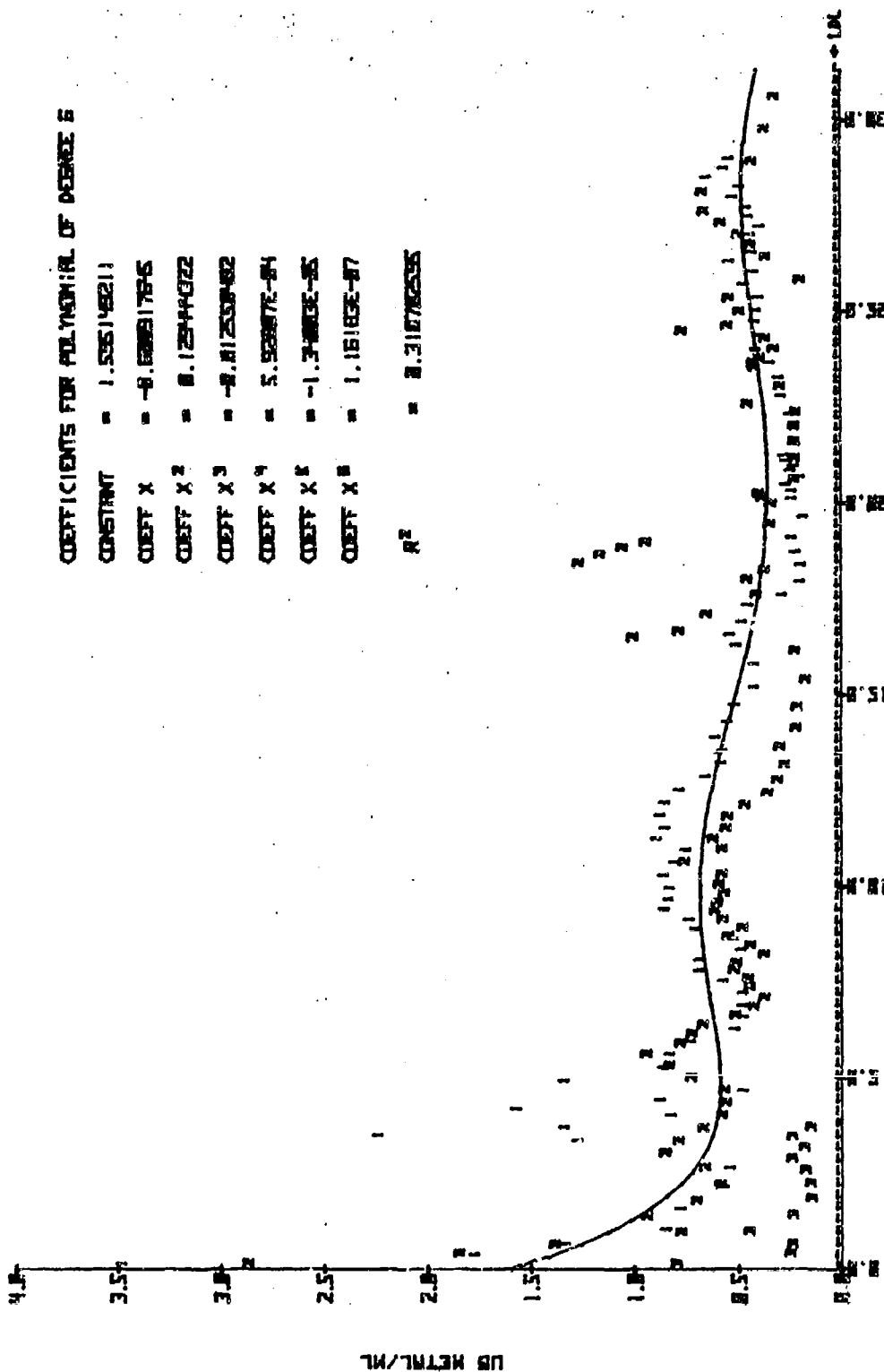
COEFF X³ = 1.53767E-03

COEFF X⁴ = -7.88506E-05

COEFF X⁵ = 1.77785E-06

COEFF X⁶ = -1.5454E-08

R² = 0.67871901



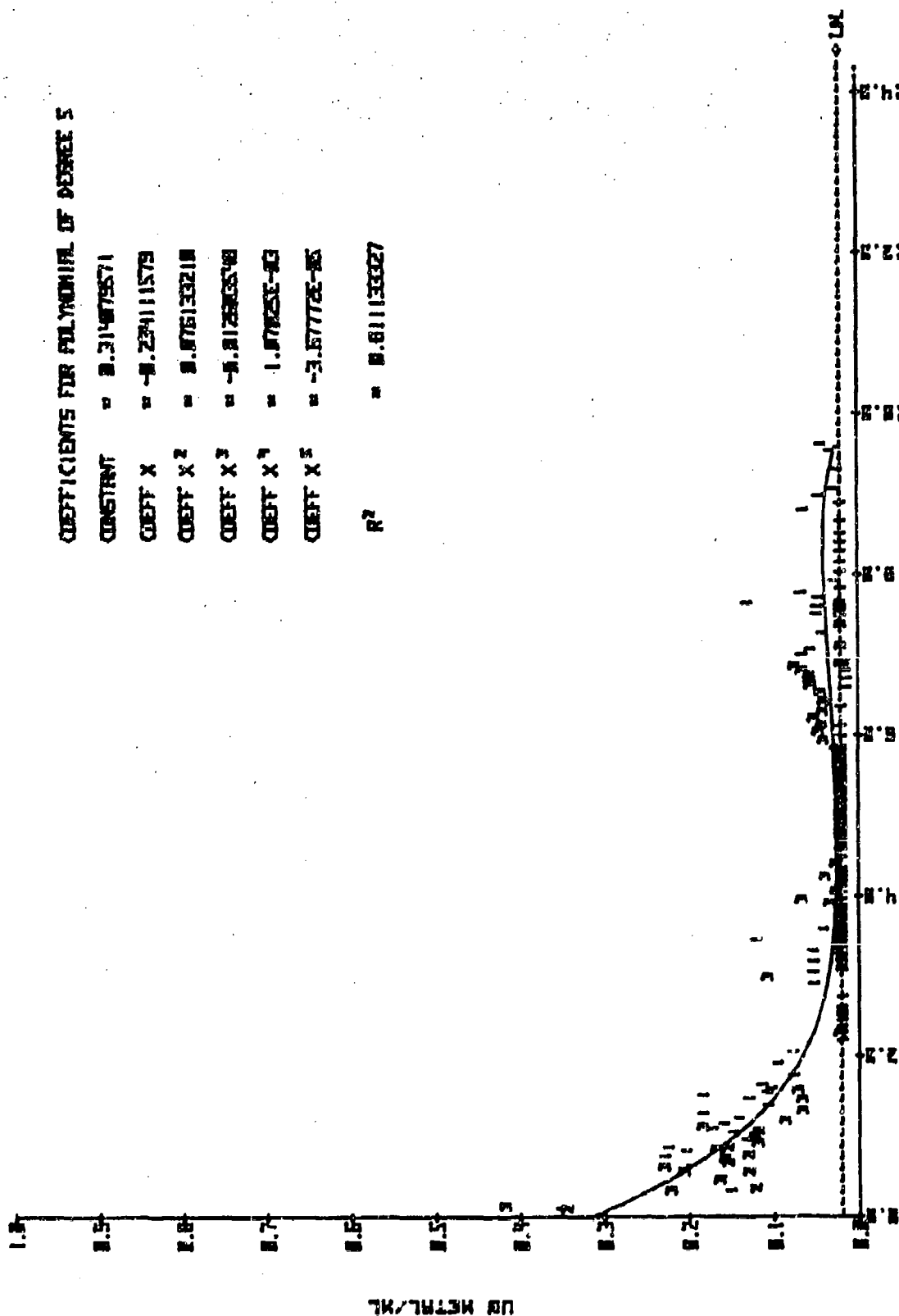
200

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 1.535148211
 COEFF X = -0.020817645
 COEFF X² = 0.12944322
 COEFF X³ = -0.012530482
 COEFF X⁴ = 5.928872-84
 COEFF X⁵ = -1.348832-85
 COEFF X⁶ = 1.151832-87
 R² = 0.310782535

CUM VOLUME (ML/500 ML SOIL)

FIGURE 120: ZINC LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY WATER



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.314879571

COEFF X = -0.234111579

COEFF X² = 0.076133210

COEFF X³ = -0.012503540

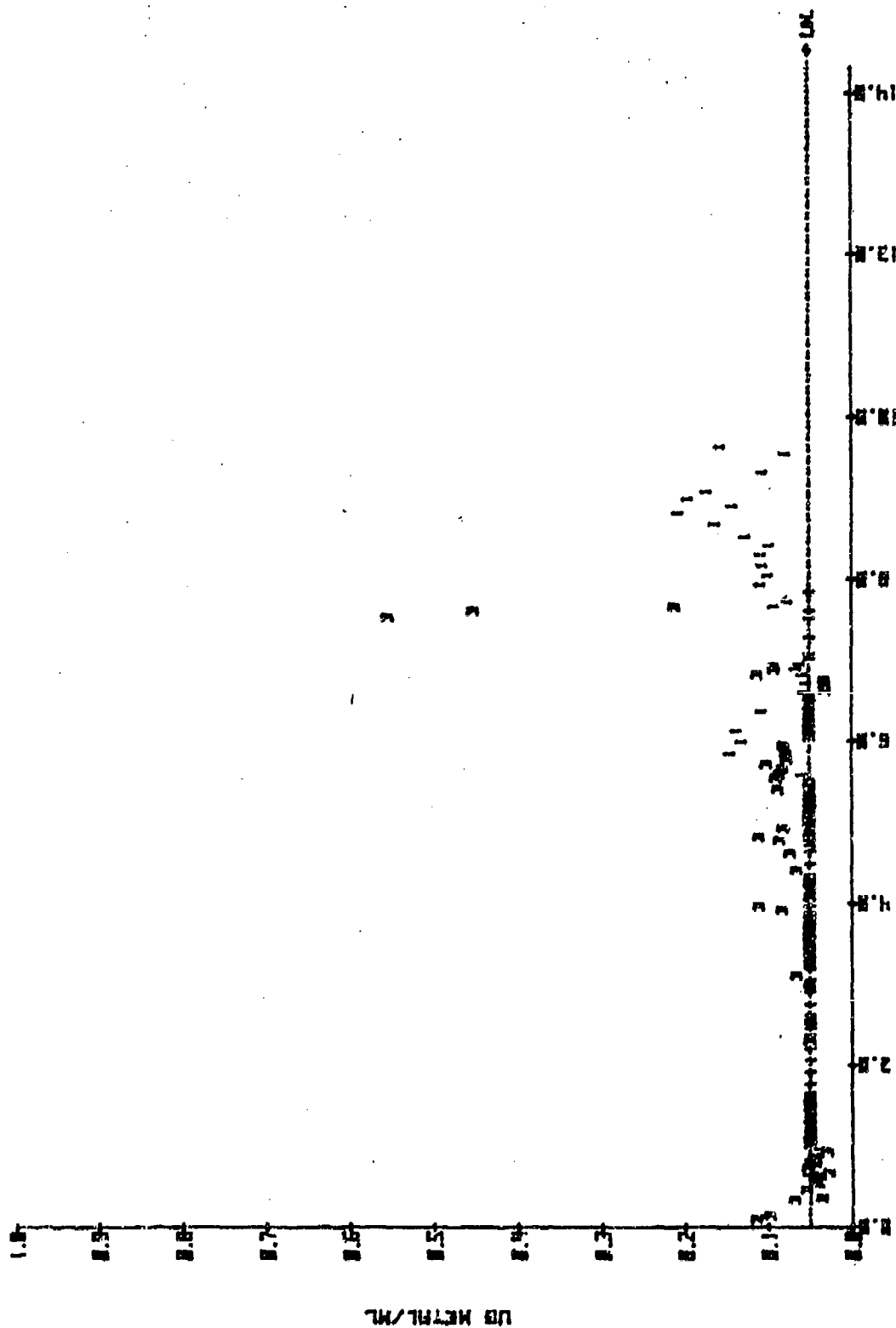
COEFF X⁴ = 1.07025E-03

COEFF X⁵ = -3.57772E-05

R² = 0.811133327

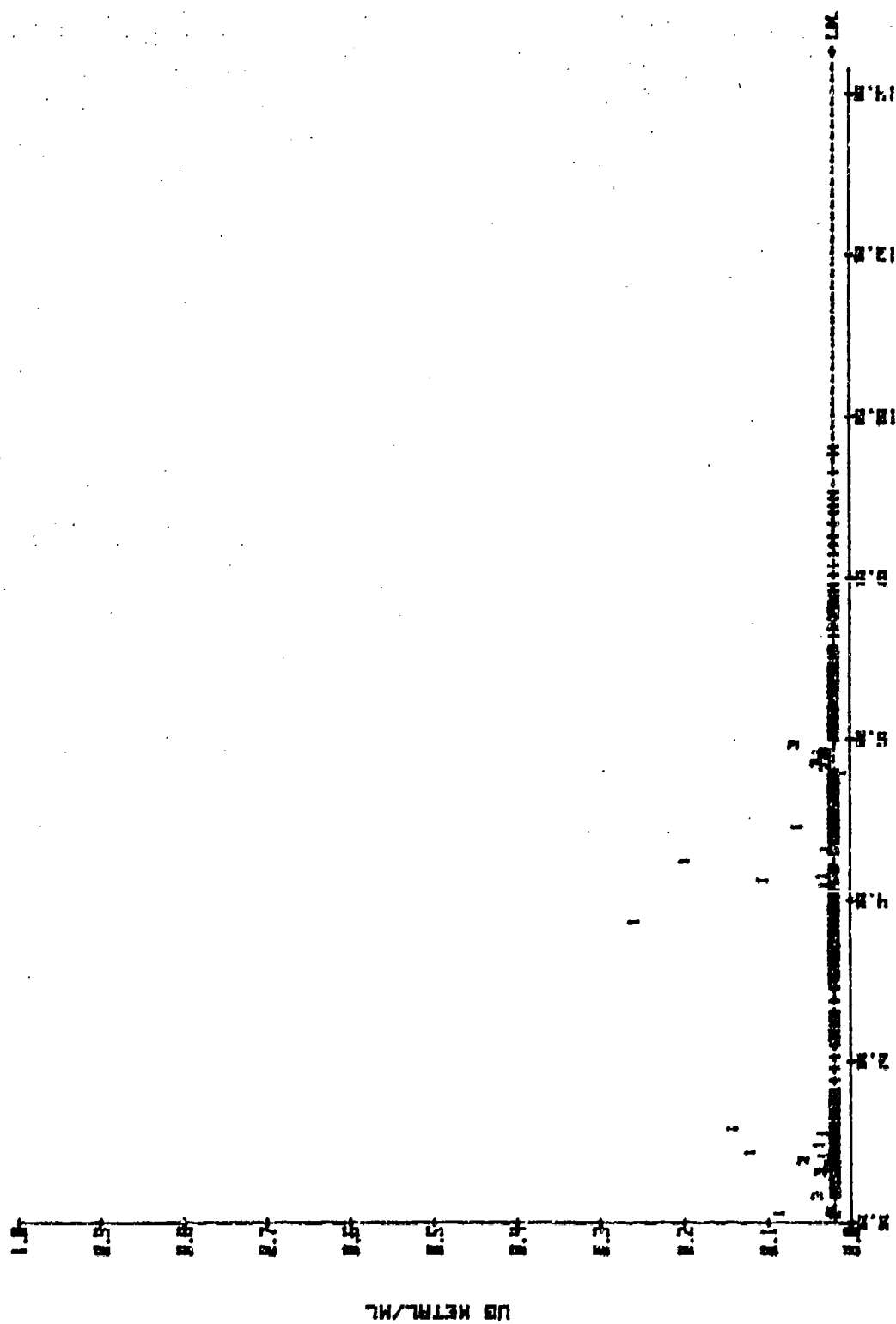
Cu VOLUME (ml/gm SOIL)

FIGURE 121: CHROMIUM LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY WATER



CON. VOLUME (ML/50g SOIL)

FIGURE 122: CHROMIUM LEACHED FROM PIMENT WASTE & KALKASKA SOIL BY WATER



MIN VOLUME (ML/CM SOIL)

FIGURE 123: COPPER LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY WATER

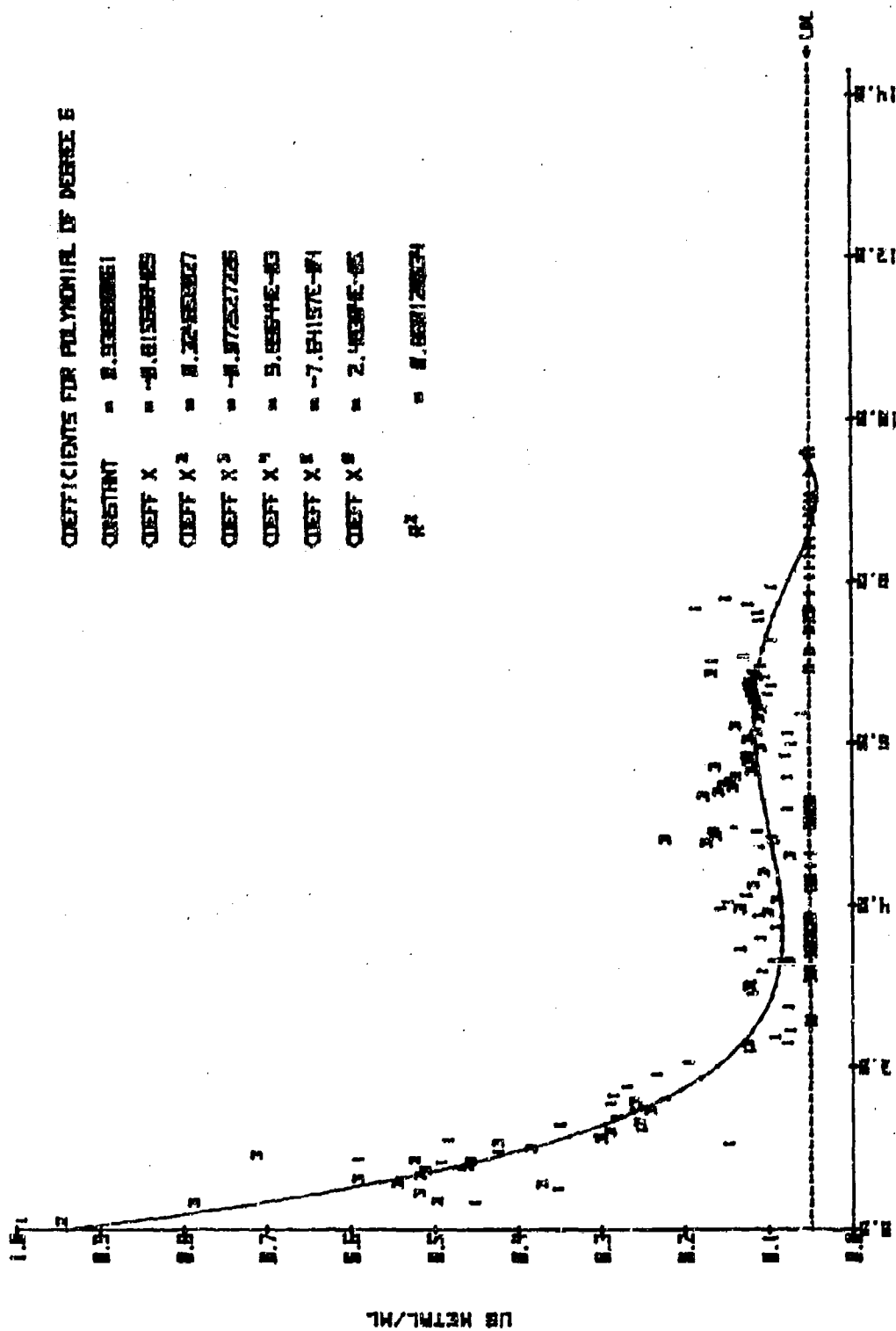


FIGURE 124: NICKEL LERCHED FROM PIGMENT WASTE & KALKASKA SOIL BY WATER

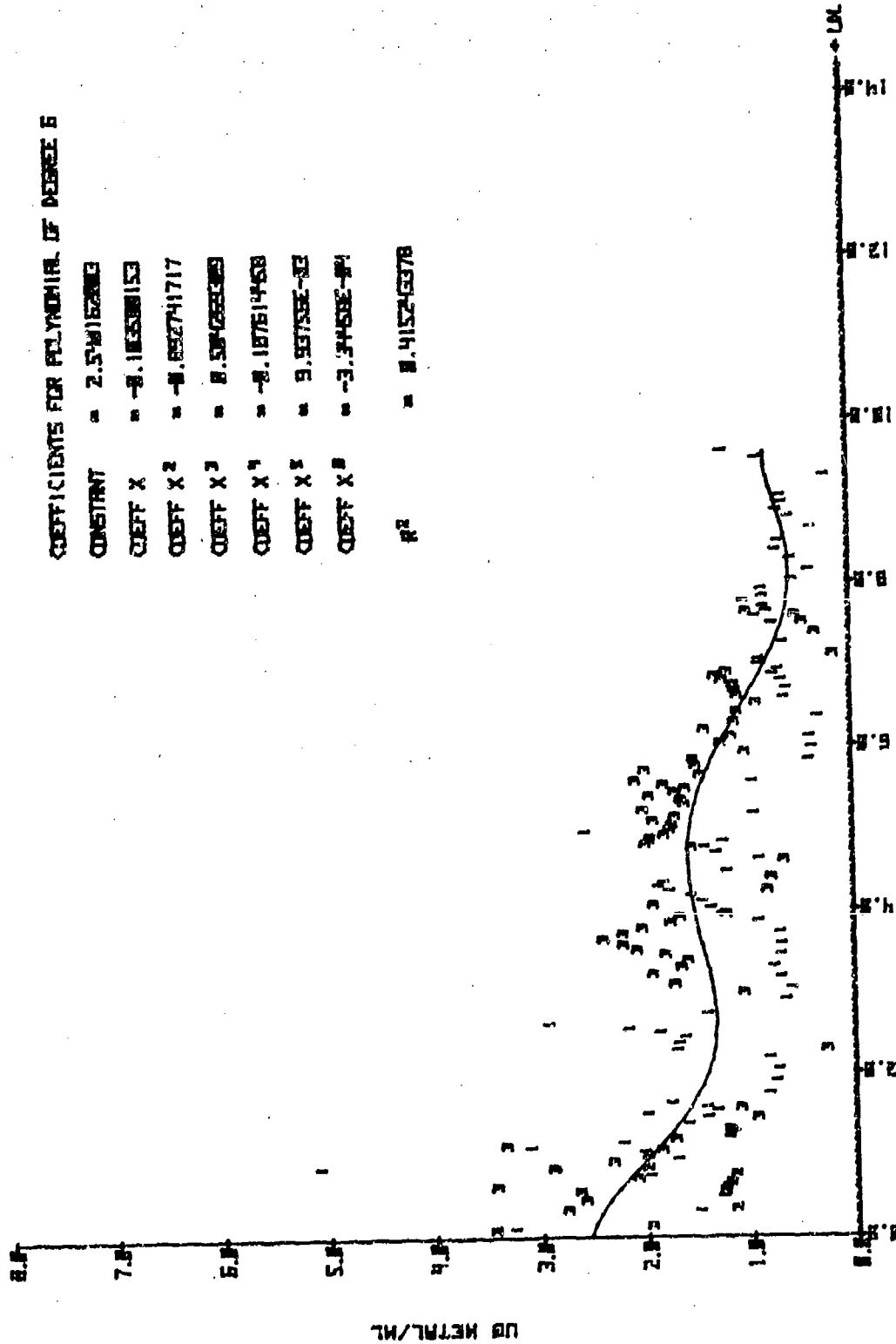


FIGURE 125 : ZINC LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY WATER

D= DAVIDSON

K= KALKASKA

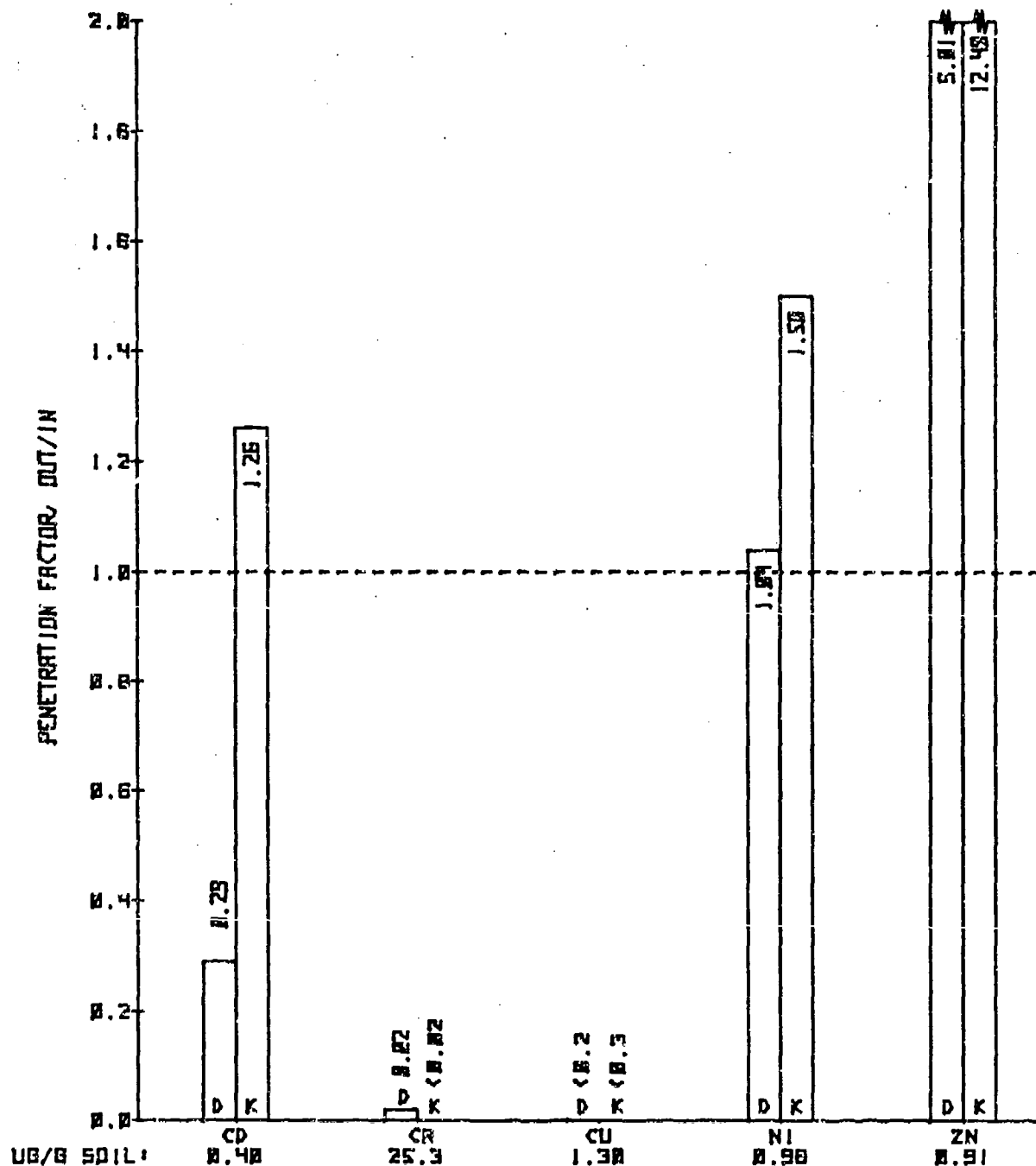


FIGURE 126: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A WATER EXTRACT OF PIGMENT WASTE

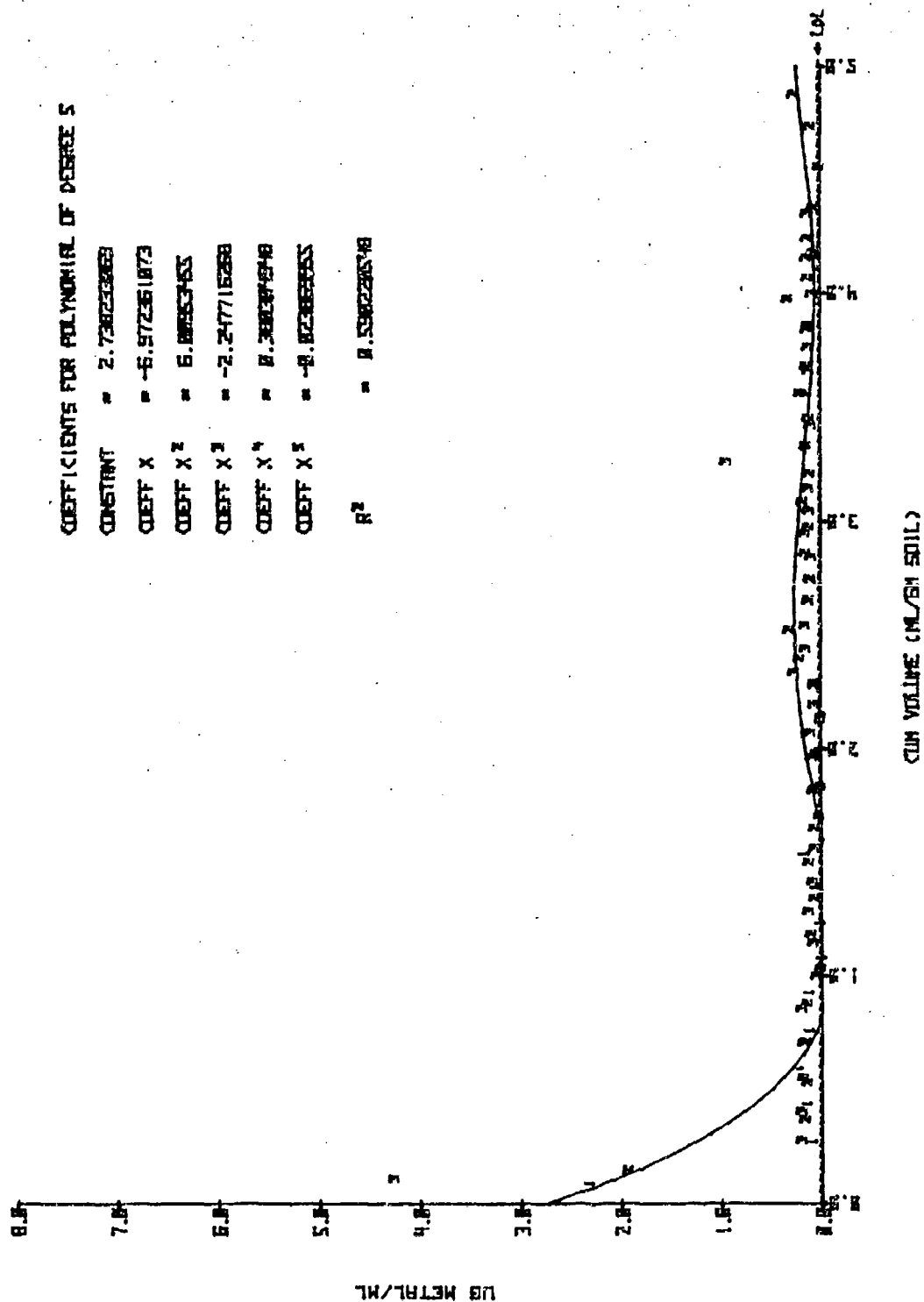
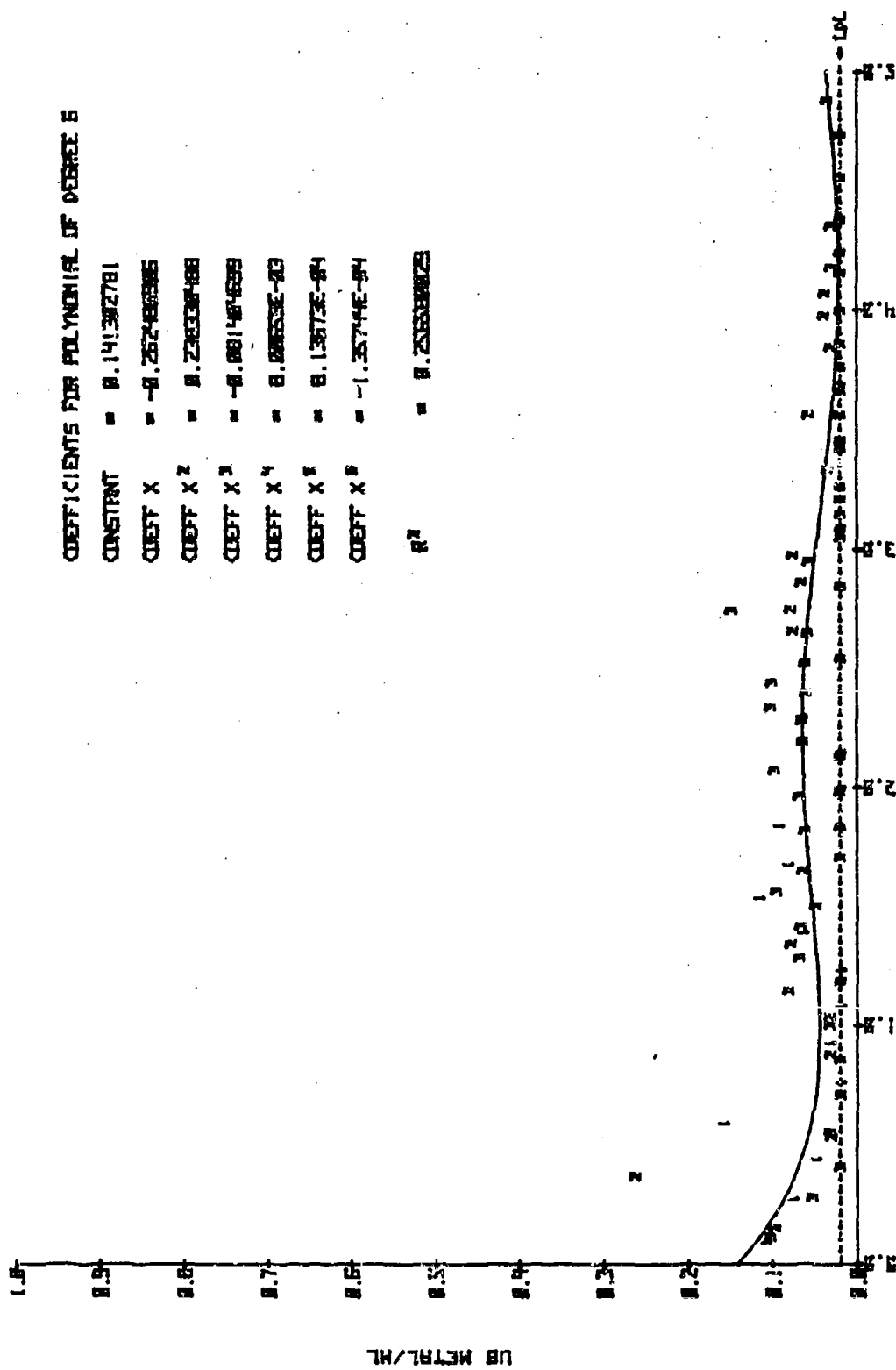


FIGURE 127: CADMIUM LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



CM VOLUME (CM/CM SOIL)

FIGURE 128: COPPER LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.141382781

COEFF X = -0.252486385

COEFF X² = 0.238384488

COEFF X³ = -0.081484639

COEFF X⁴ = 0.0085356403

COEFF X⁵ = 0.135735484

COEFF X⁶ = -1.357445484

R² = 0.253388023

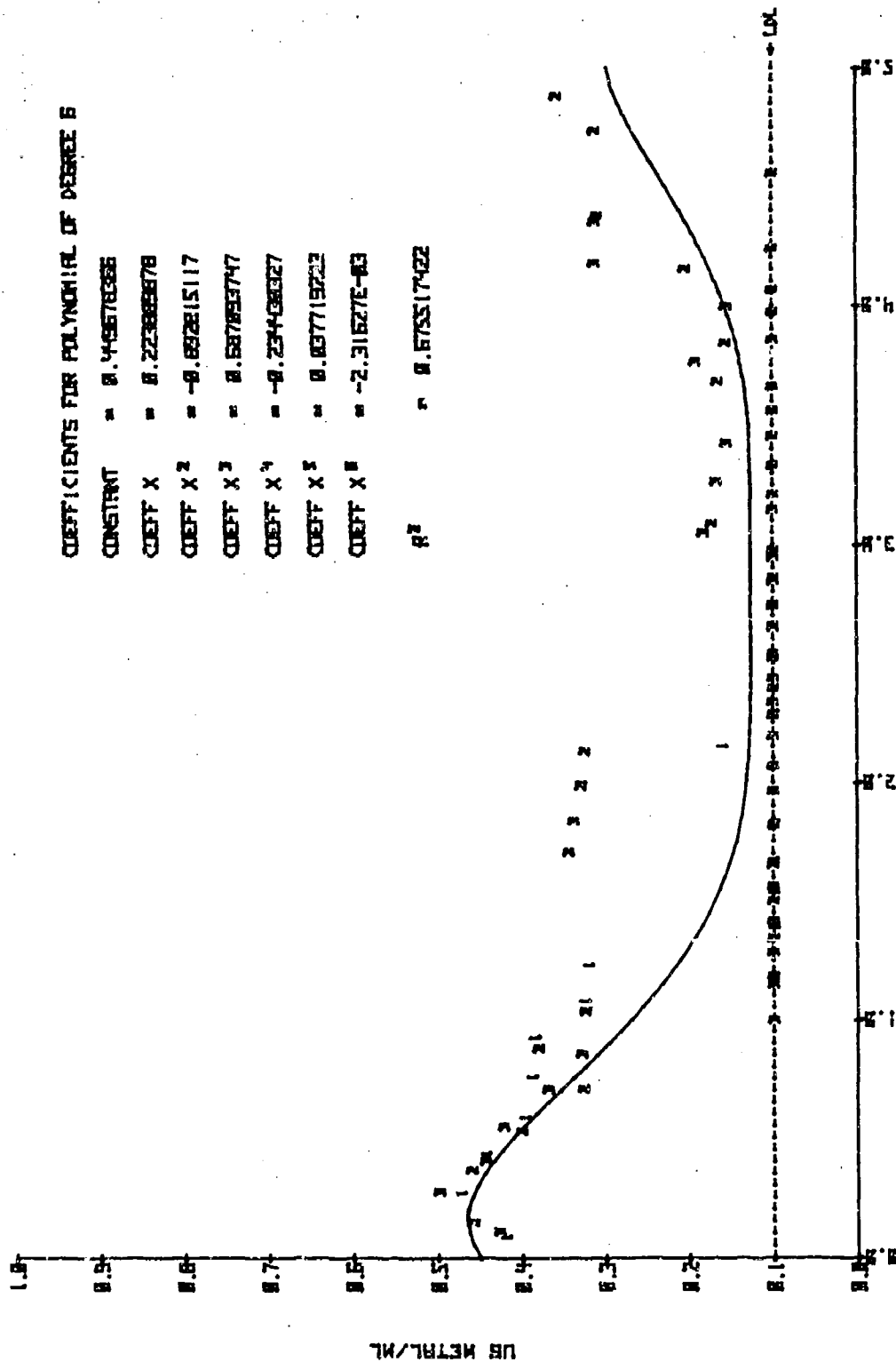
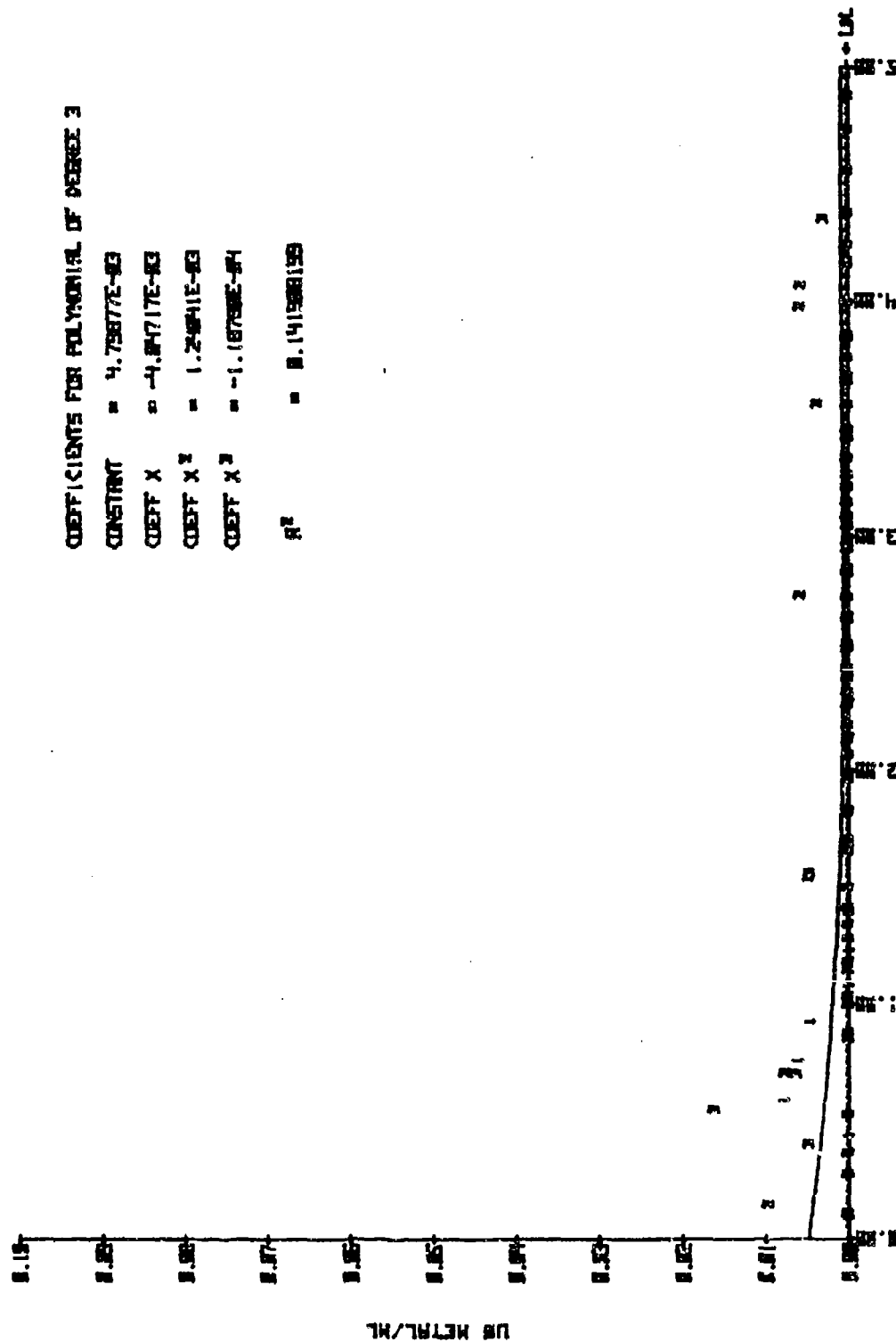


FIGURE 129: LEAD LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

CONSTANT = 4.75877E-03

COEFF X = -4.84717E-03

COEFF X² = 1.24841E-03

COEFF X³ = -1.18788E-04

R² = 0.141988199

CIN VOLUME (ML/GR SOIL)

FIGURE 130: MERCURY LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.108387403
 COEFF X = 0.541757462
 COEFF X² = -0.27722594
 COEFF X³ = 0.01453453
 COEFF X⁴ = 0.015621359
 COEFF X⁵ = -1.30875E-03
 R² = 0.354621552

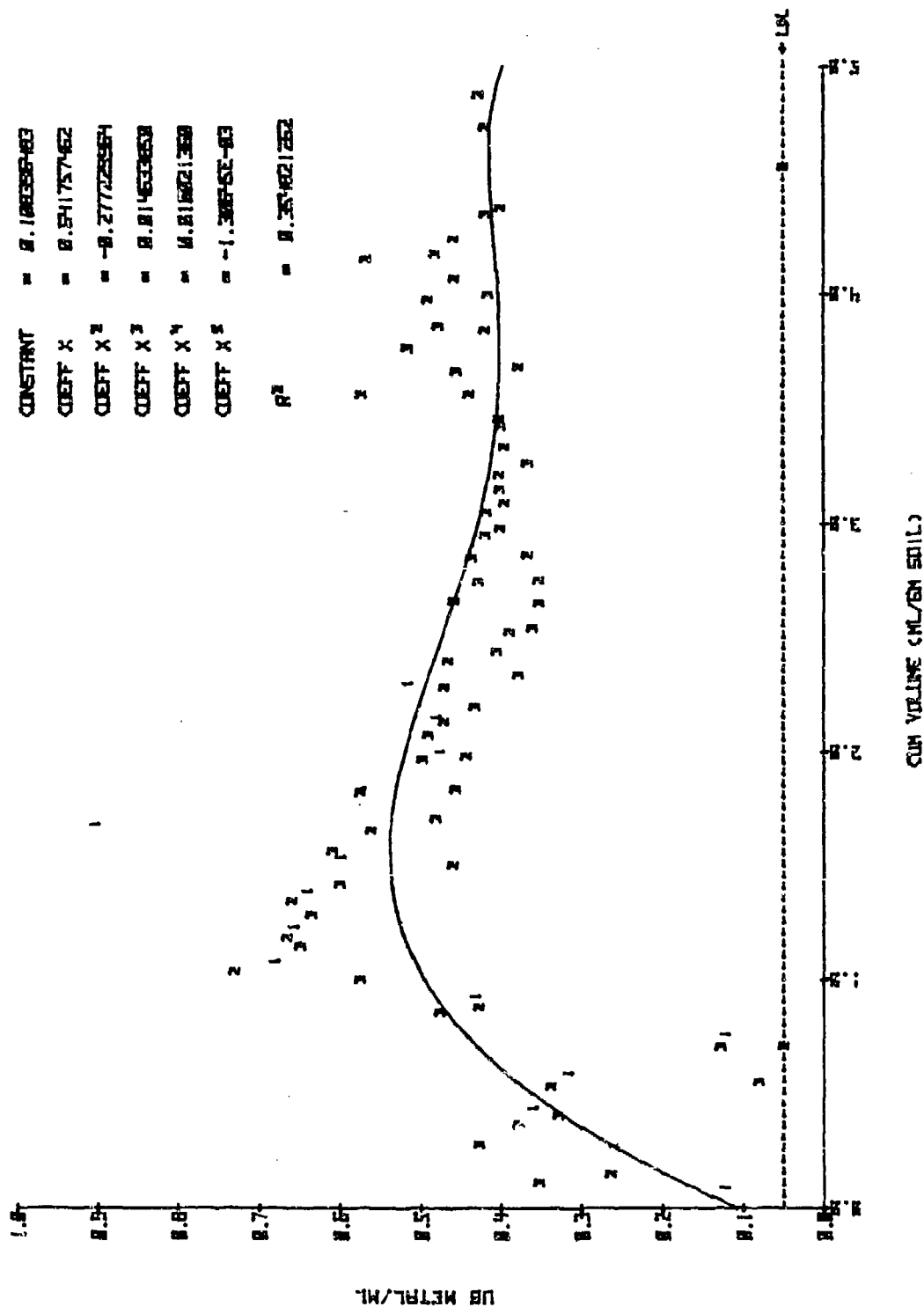


FIGURE 131: NICKEL LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

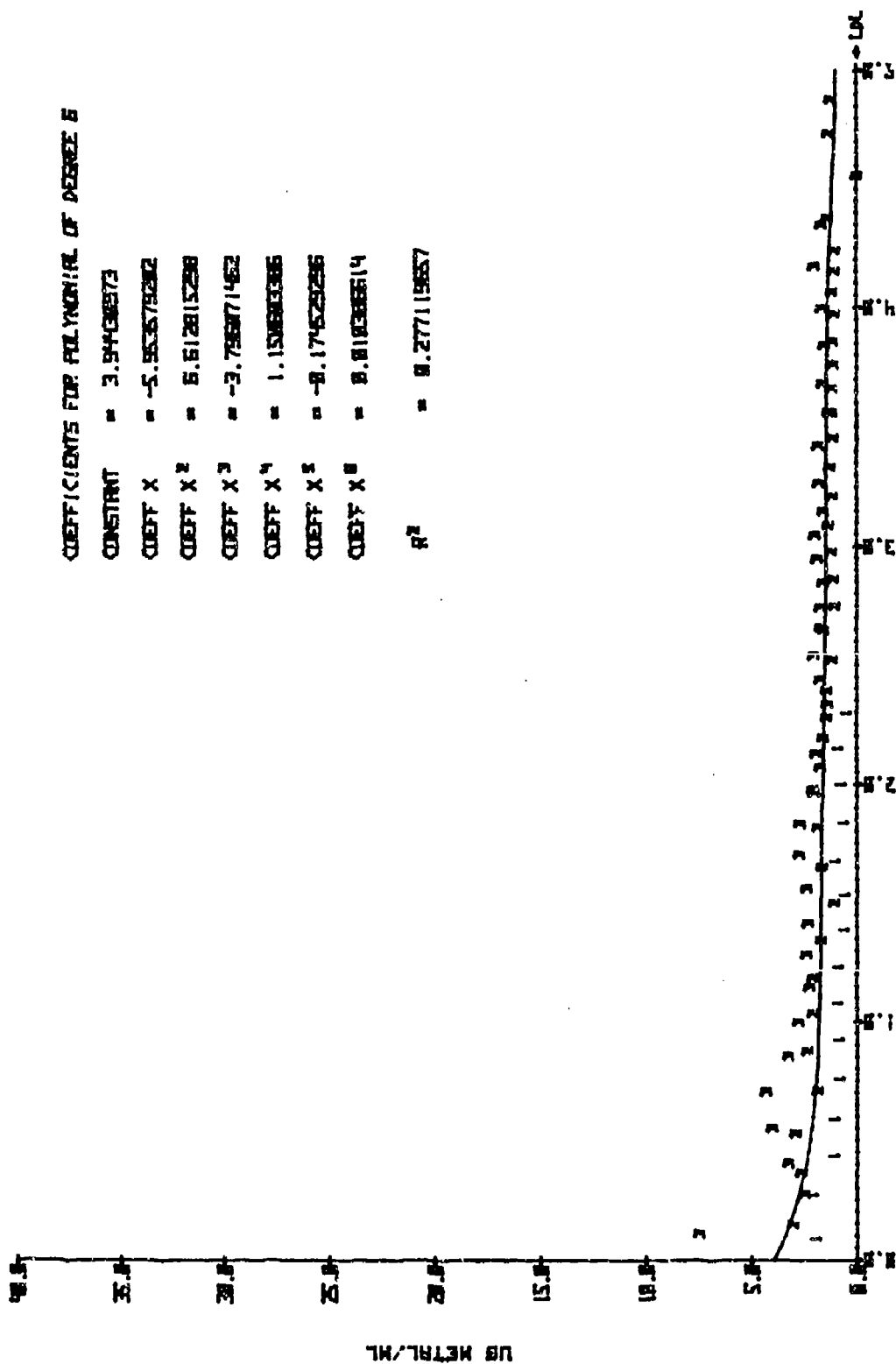


FIGURE 132: ZINC LEACHED FROM PIEMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 3.94438573
 COEFF X = -5.953579282
 COEFF X² = 6.612815298
 COEFF X³ = -3.798871452
 COEFF X⁴ = 1.150883386
 COEFF X⁵ = -8.174529286
 COEFF X⁶ = 8.818386614

R² = 0.277119657

This will be discussed in the supplemental report. Because the results are sporadic, the regression equation for the mercury penetration through the soil is poor but it does provide an estimate of the weight of metal applied to the column and found in the soil column effluent. In a few of the samples, the concentration of mercury exceeded the drinking water standard.

Nickel was found in most samples in substantial concentrations. Zinc exceeded the standard only once.

Figures 133 through 138 are plots of cadmium, chromium, copper, lead, nickel and zinc leached by municipal landfill leachate from inorganic pigment waste and penetrating Kalkaska soil. Zinc results initially were fairly scattered but a good fit to the derived regression equation was obtained. Cadmium, lead and chromium were found in appreciable concentrations, in that order. Copper and nickel were present at lower levels.

Figure 139 shows the fraction of the input of each metal, from the municipal landfill leachate leaching of the inorganic pigment waste, that passes through each soil.

pH and Conductance Measurements--Figures 140 through 147 are plots of pH and specific conductance. The results show that when leached by water, the pigment waste caused little change in the pH of the soil column effluent. The values were close to the control column pH values of both soils. However, conductance values of the water-leached columns indicate that the waste leachate passed through the soil columns readily and in addition, probably leached many naturally occurring ions from the soil. The conductance values found in the soil control column effluent samples were very low when leached with water.

The municipal landfill leachate waste samples altered the pH of the column effluents from both soils more than when water was used. The pH values found in the Kalkaska soil effluent were close to the pH of the leachate alone. The specific conductance values were high throughout the leaching period for both soils while the conductance of the water leached samples dropped off rapidly.

Water Base Paint Waste--

Water Extracts--Figures 148 and 149 are plots of cadmium and zinc leached by water from water base paint waste and penetrating Davidson soil. The appearance of cadmium in the samples is periodic which may indicate that different forms of the metal are present in the waste and distributed differently in the soil. Zinc was found in the soil leachate samples in substantial concentrations but did not exceed the standard. Copper was found in only a few samples. As a result, the copper data was not plotted.

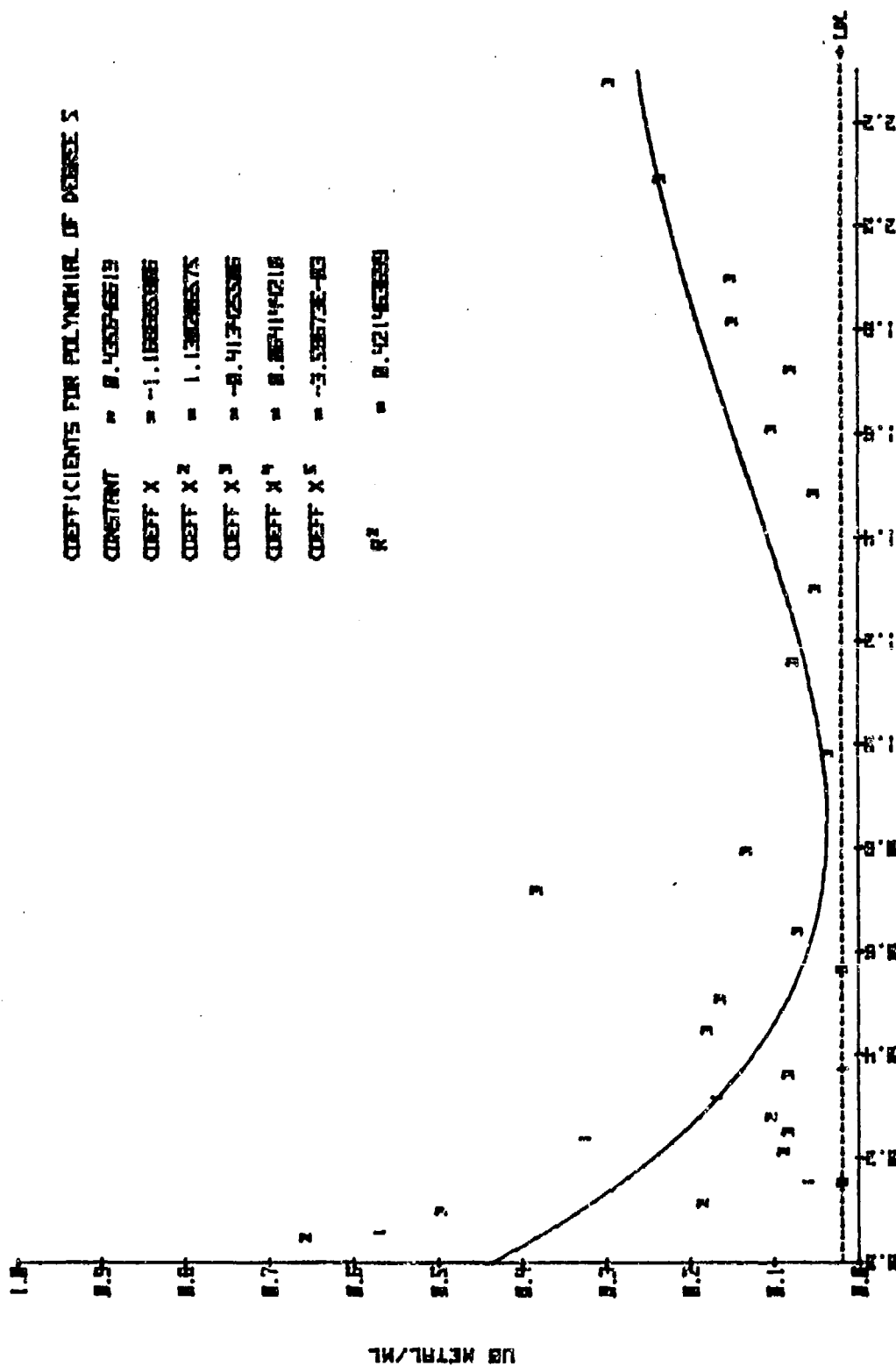
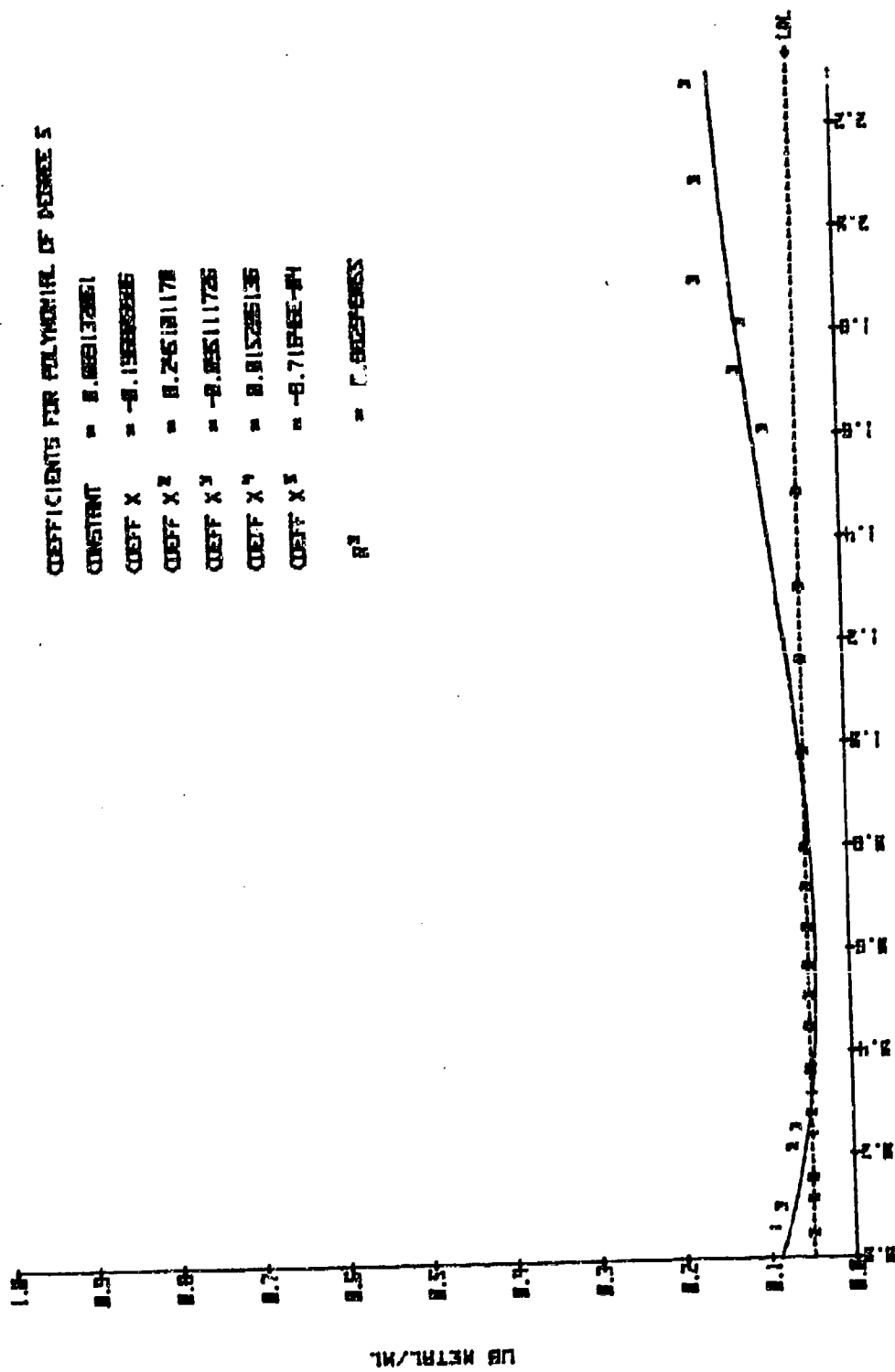


FIGURE 133: CADMIUM LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



CLAY VOLUME (ML/G SOIL)

FIGURE 134 : CHROMIUM LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

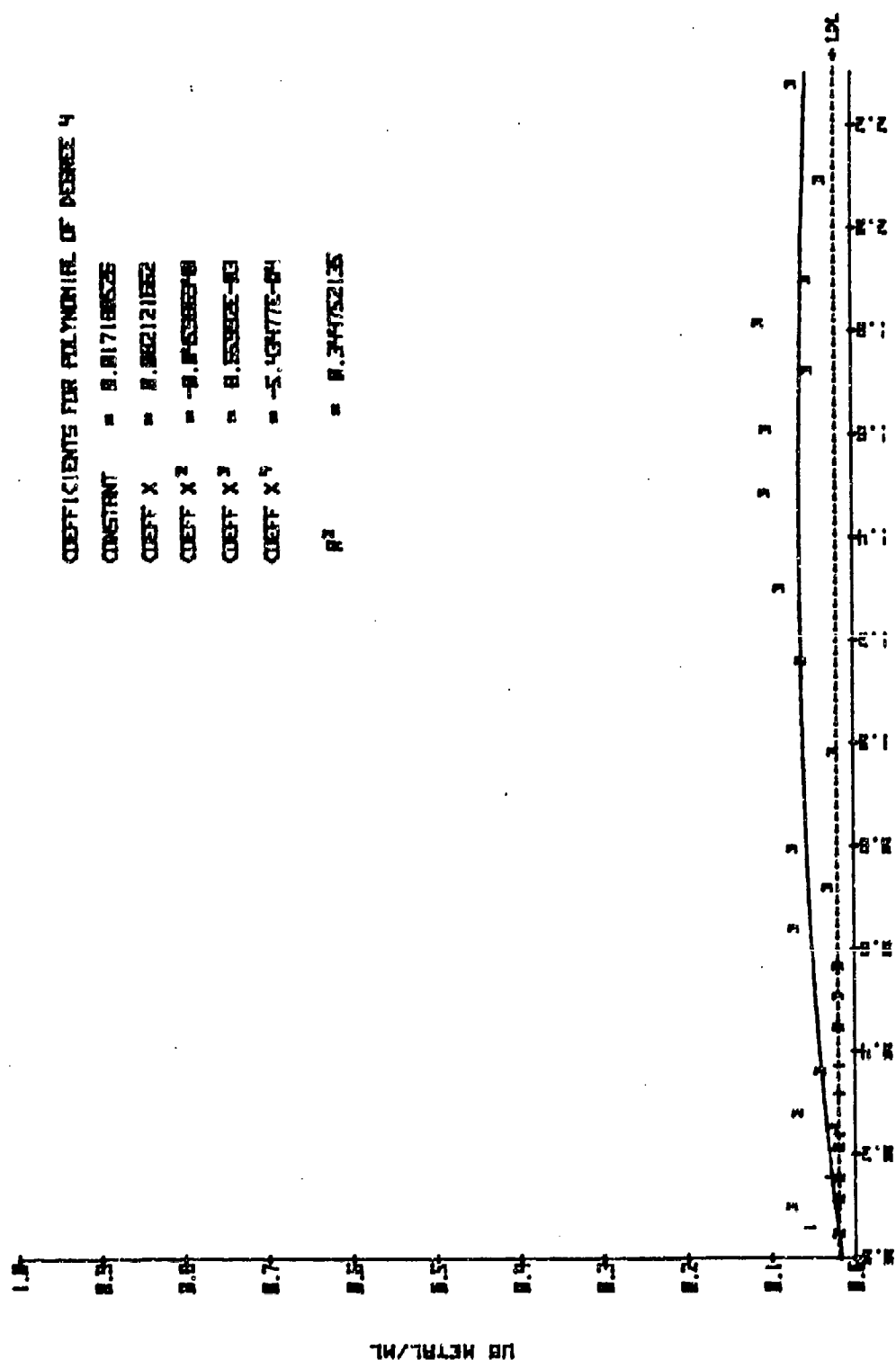


FIGURE 135: COPPER LEACHED FROM PIGMENT WASTE & KILNASHA SOIL BY LANDFILL LEACHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 4

CONSTANT = 0.017186525

COEFF X = 0.002121862

COEFF X² = -0.000000000

COEFF X³ = 0.000000000

COEFF X⁴ = -5.404775-04

R² = 0.999752135

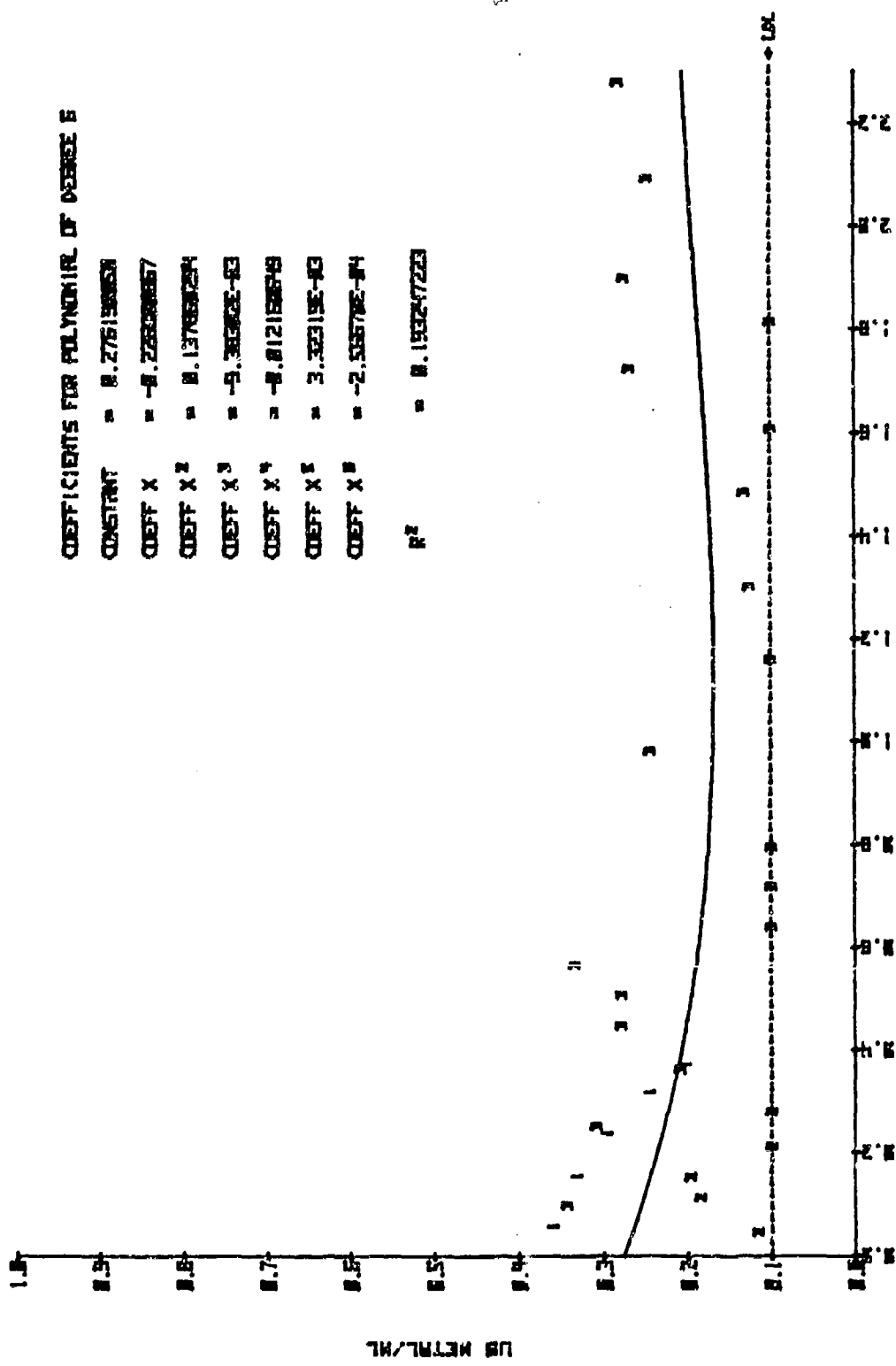


FIGURE 136: LEAD LELNCHED FROM PIMENT WASTE & KALKASKA SOIL BY LANDFILL LERCHATE

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.276190658

COEFF X = -0.26300667

COEFF X² = 0.137060294

COEFF X³ = -0.363025-03

COEFF X⁴ = -0.0121506749

COEFF X⁵ = 3.32319E-03

COEFF X⁶ = -2.55670E-04

R² = 0.93247223

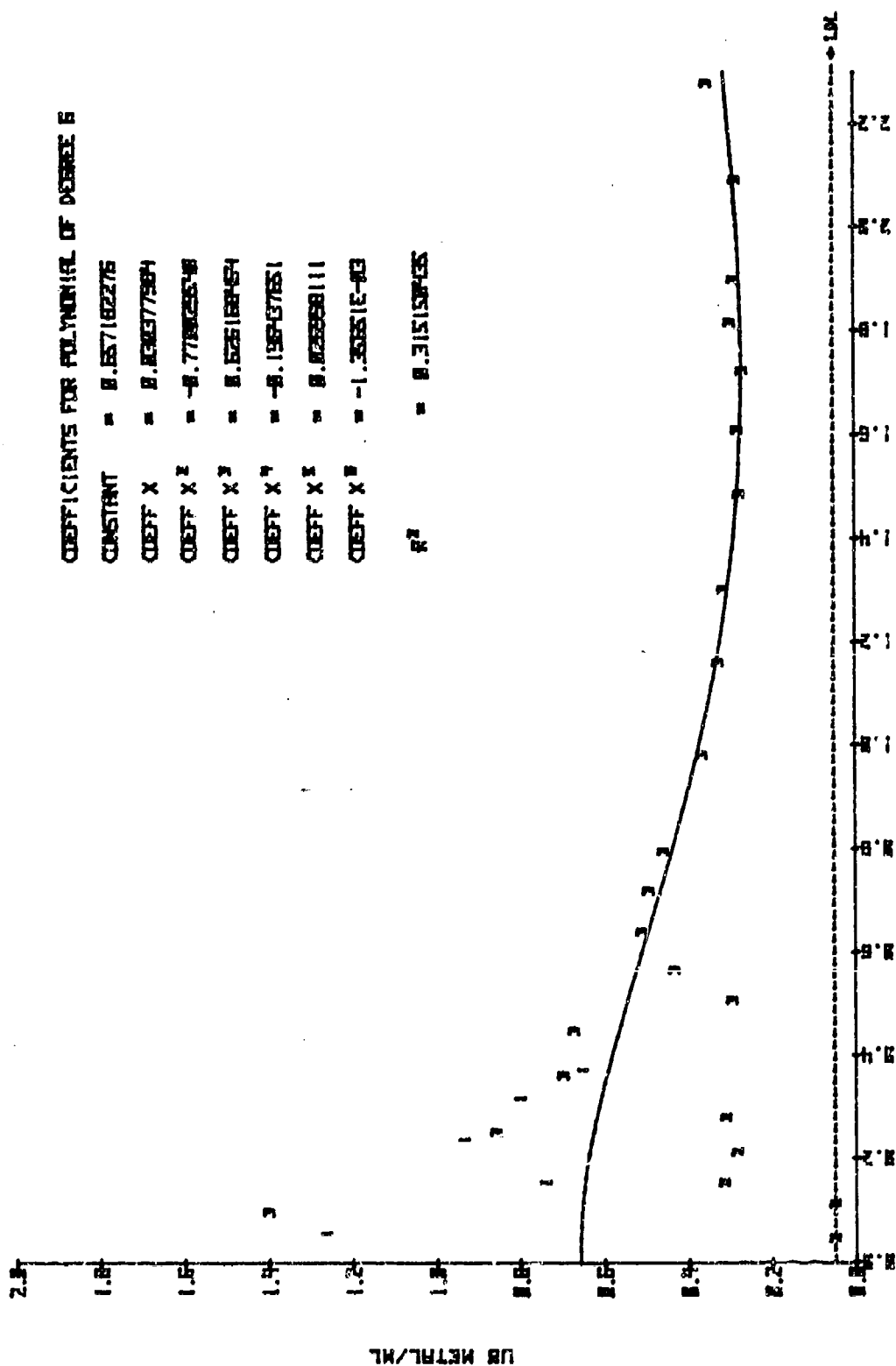


FIGURE 137: NICKEL LERCHED FROM PIGMENT WASTE & KALKASKA SOIL BY LANDFILL LERCHATE

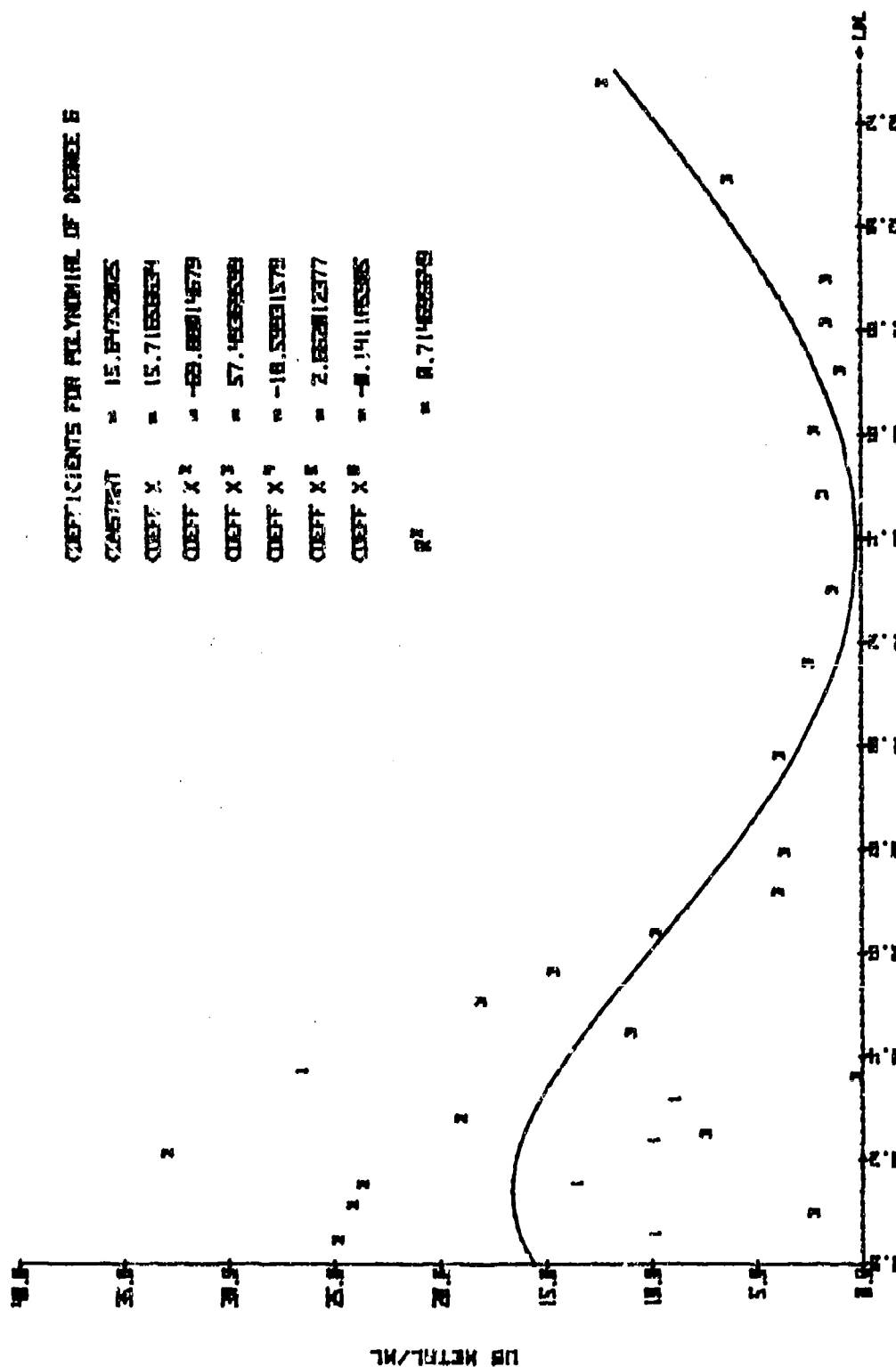


FIGURE 138: ZINC LERCHED FROM PIGMENT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

D= DAVIDSON

K= KALKASKA

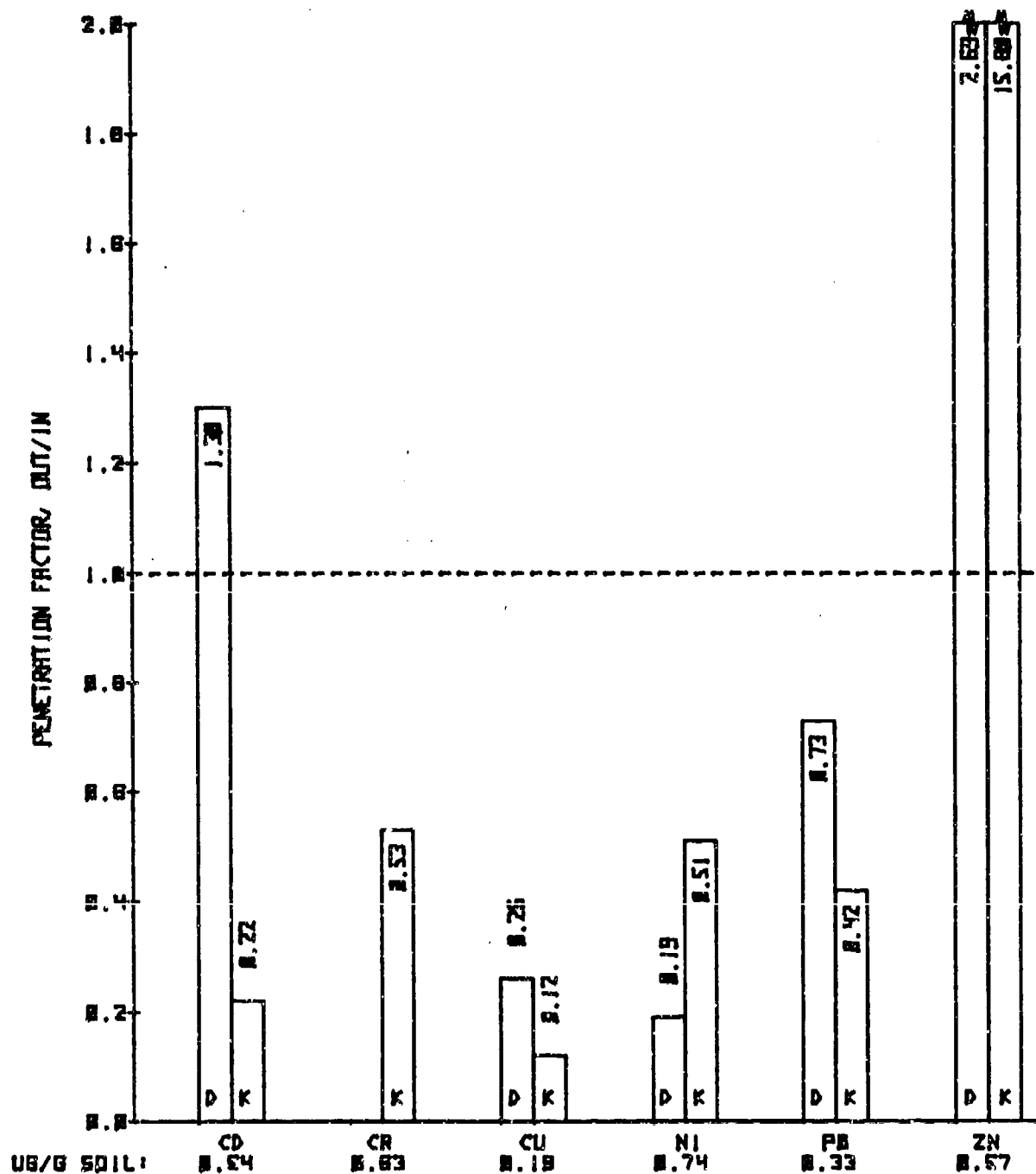


FIGURE 139: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A LANDFILL LEACHATE EXTRACT OF PIGMENT WASTE

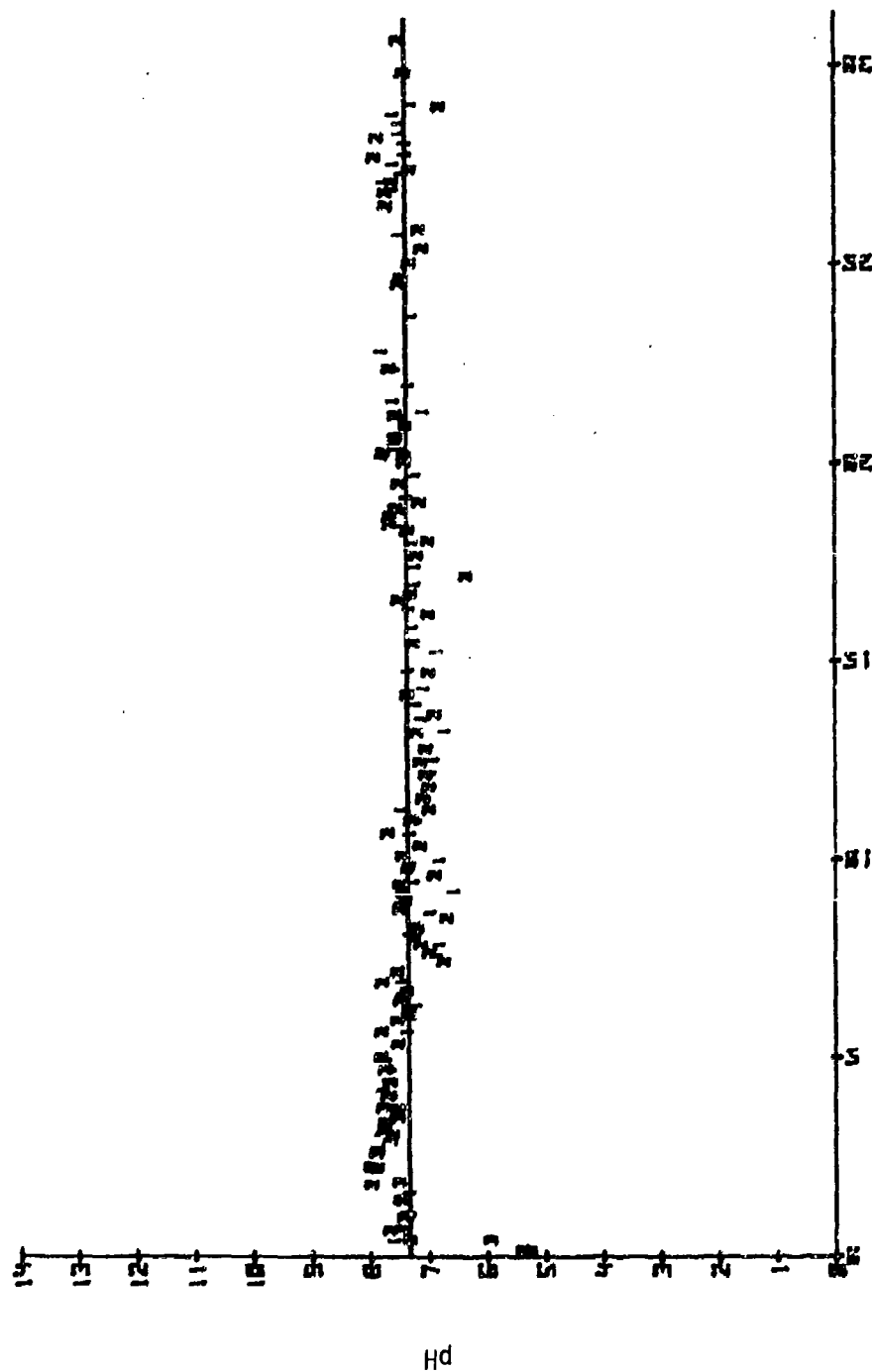


FIGURE 140: pH OF SOLUTION LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY WATER

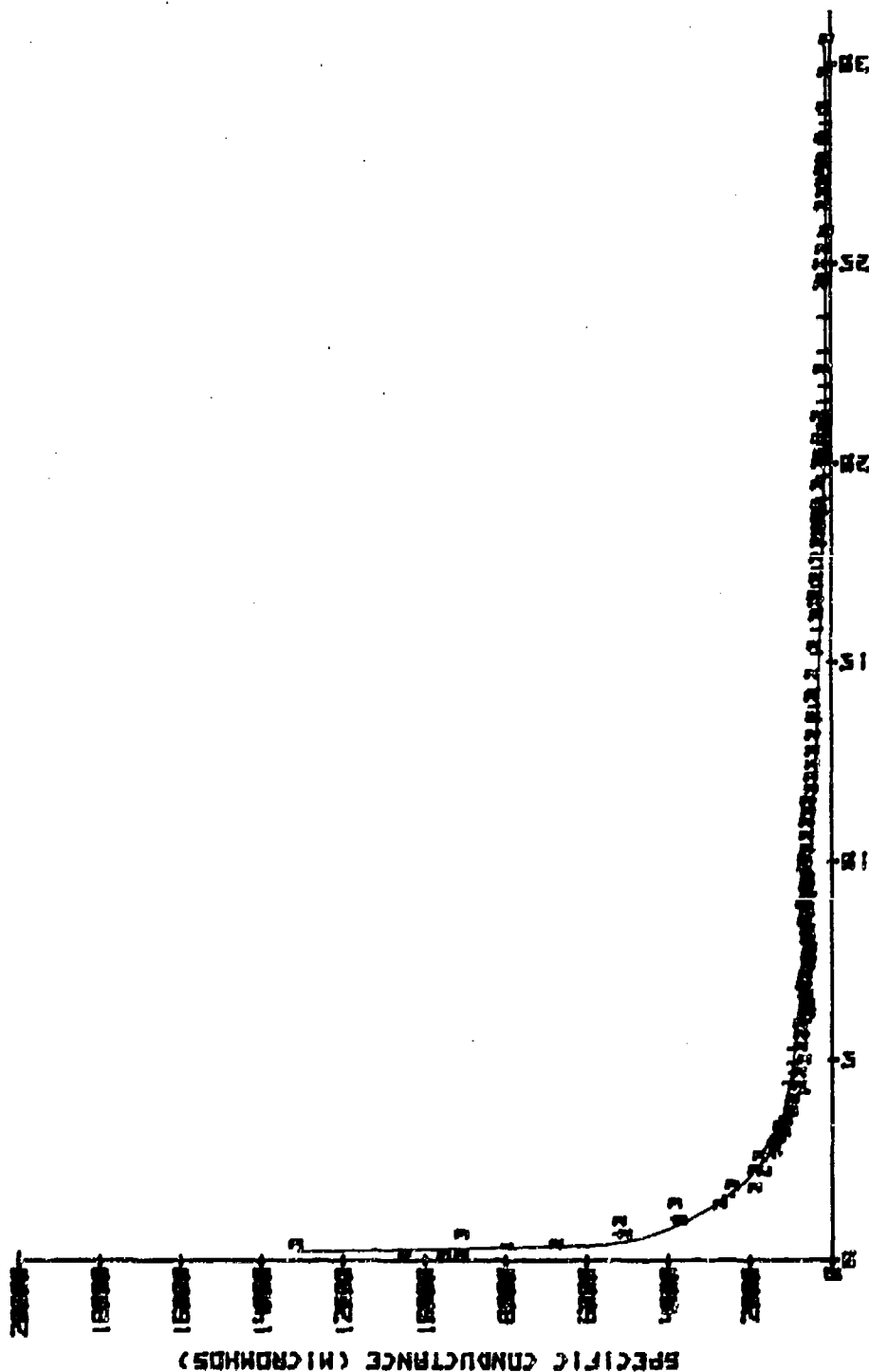


FIGURE 141: CONDUCTANCE OF SOLUTION LEACHED FROM PIGMENT
WASTE & DAVIDSON SOIL BY WATER

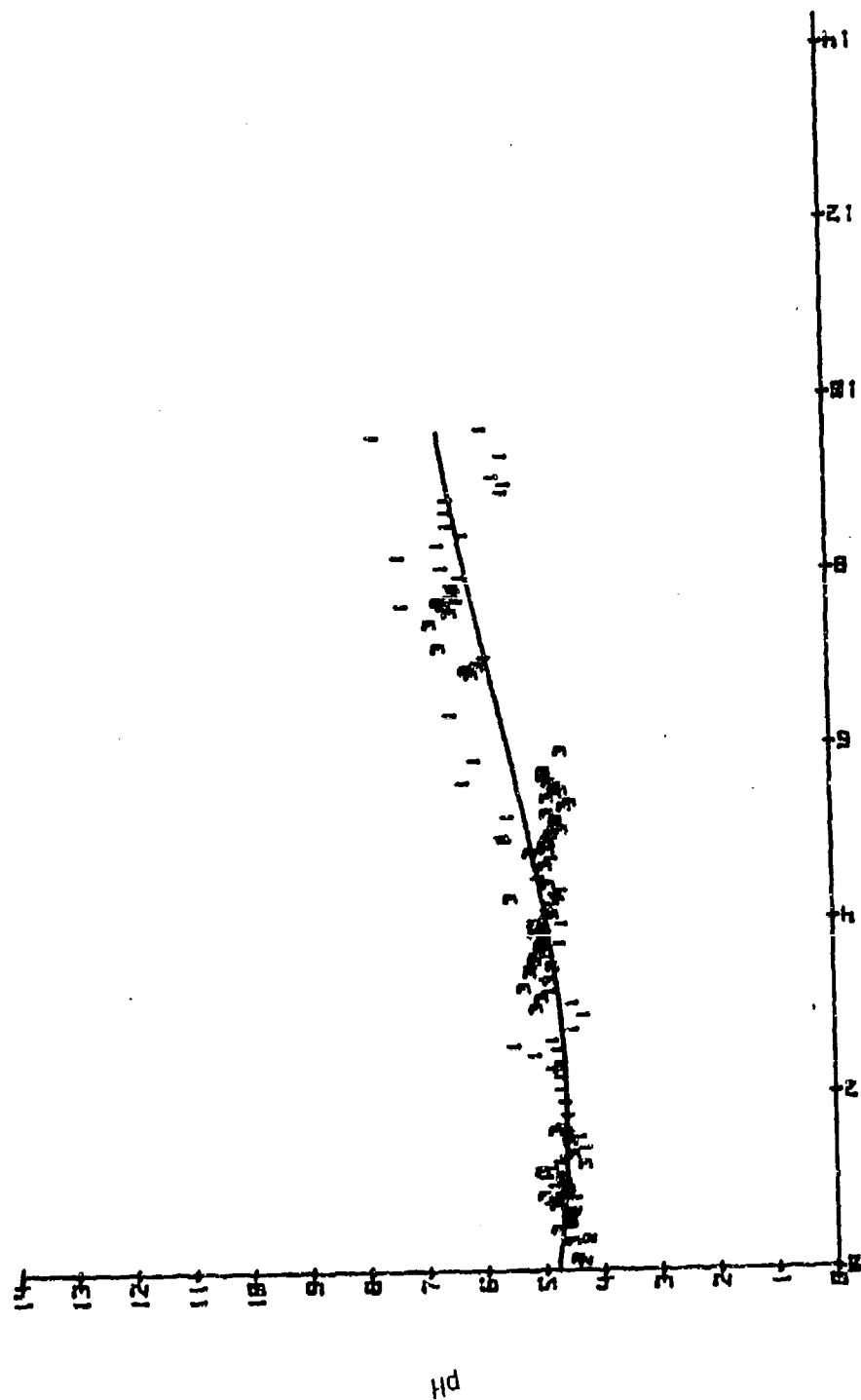
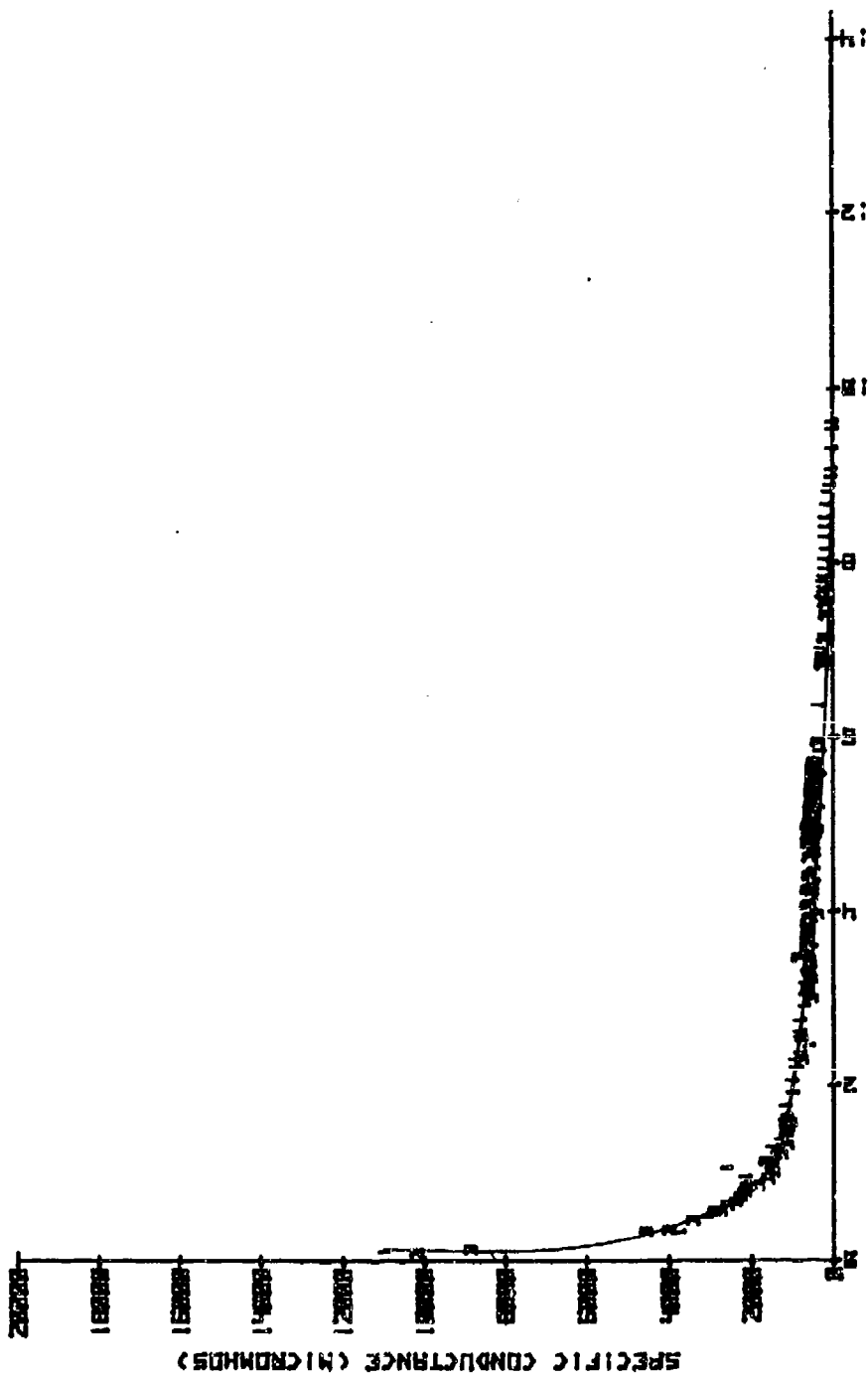
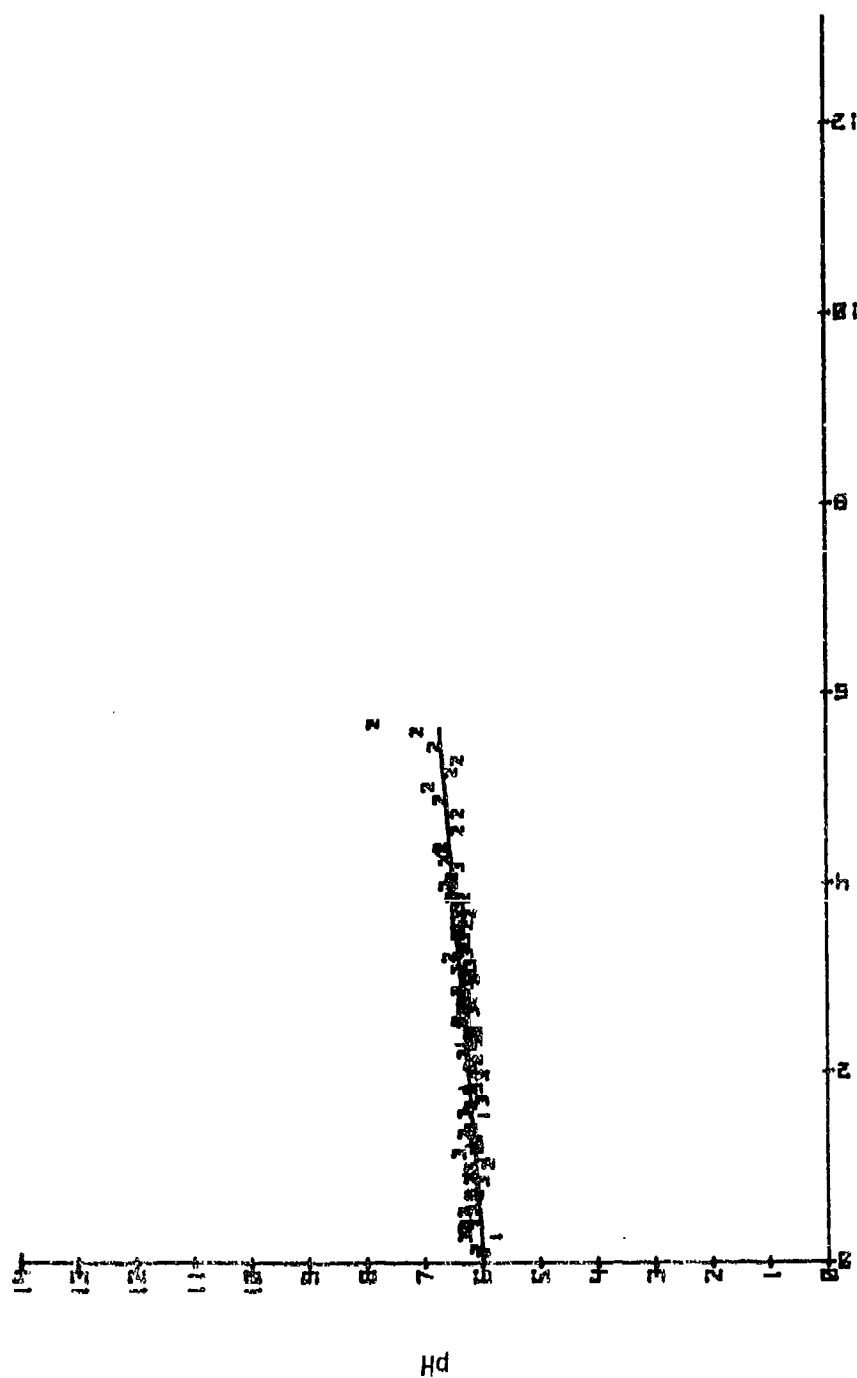


FIGURE 142: pH OF SOLUTION LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY WATER



CATION VALUE (ML/GM SOIL)
 FIGURE 143: CONDUCTANCE OF SOLUTION LEACHED FROM PIGMENT
 WASTE & KALKASKA SOIL BY WATER



CUM VOLUME (ML/GM SOIL)

FIGURE 144 : pH OF SOLUTION LEACHED FROM PIGMENT
WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

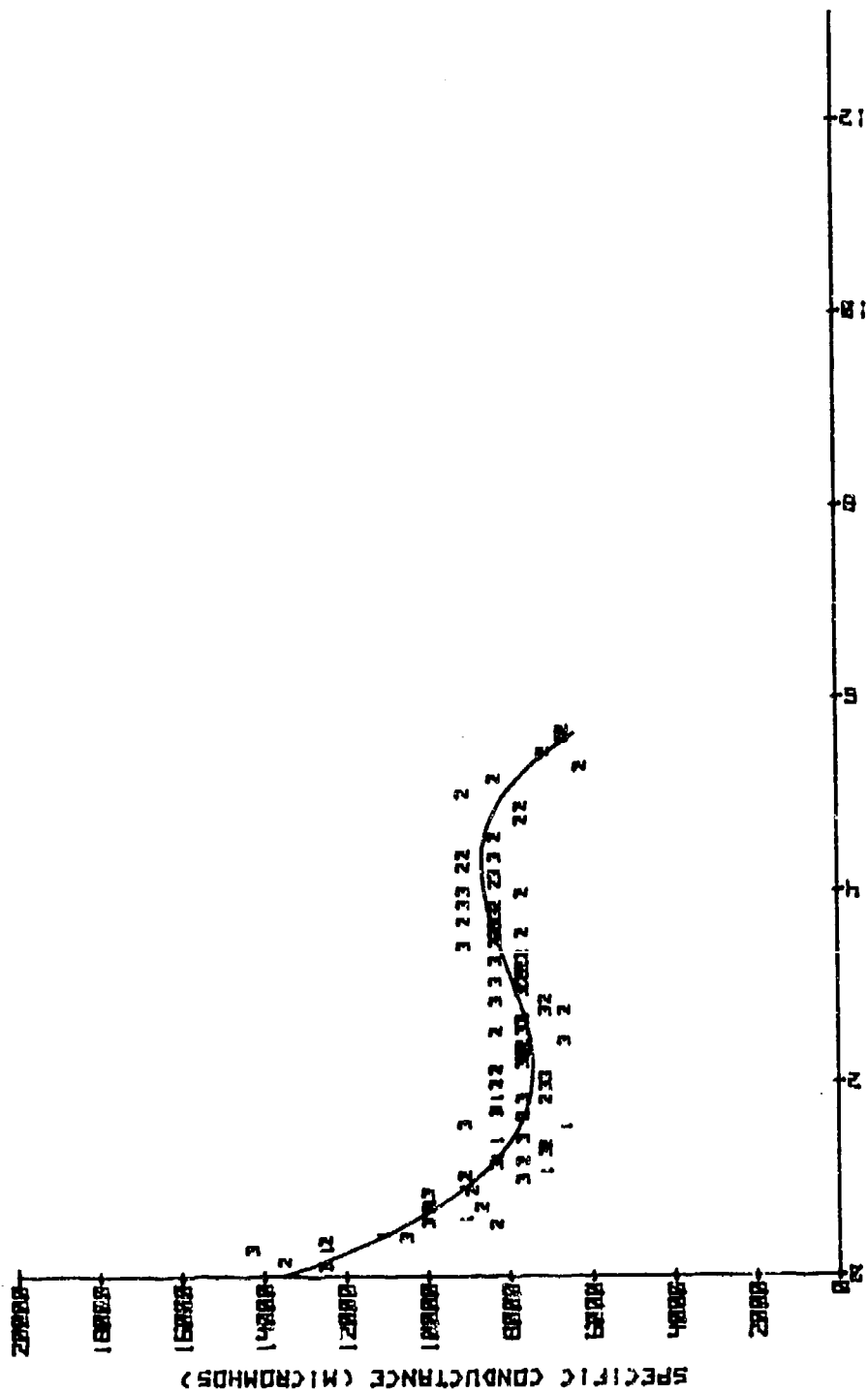
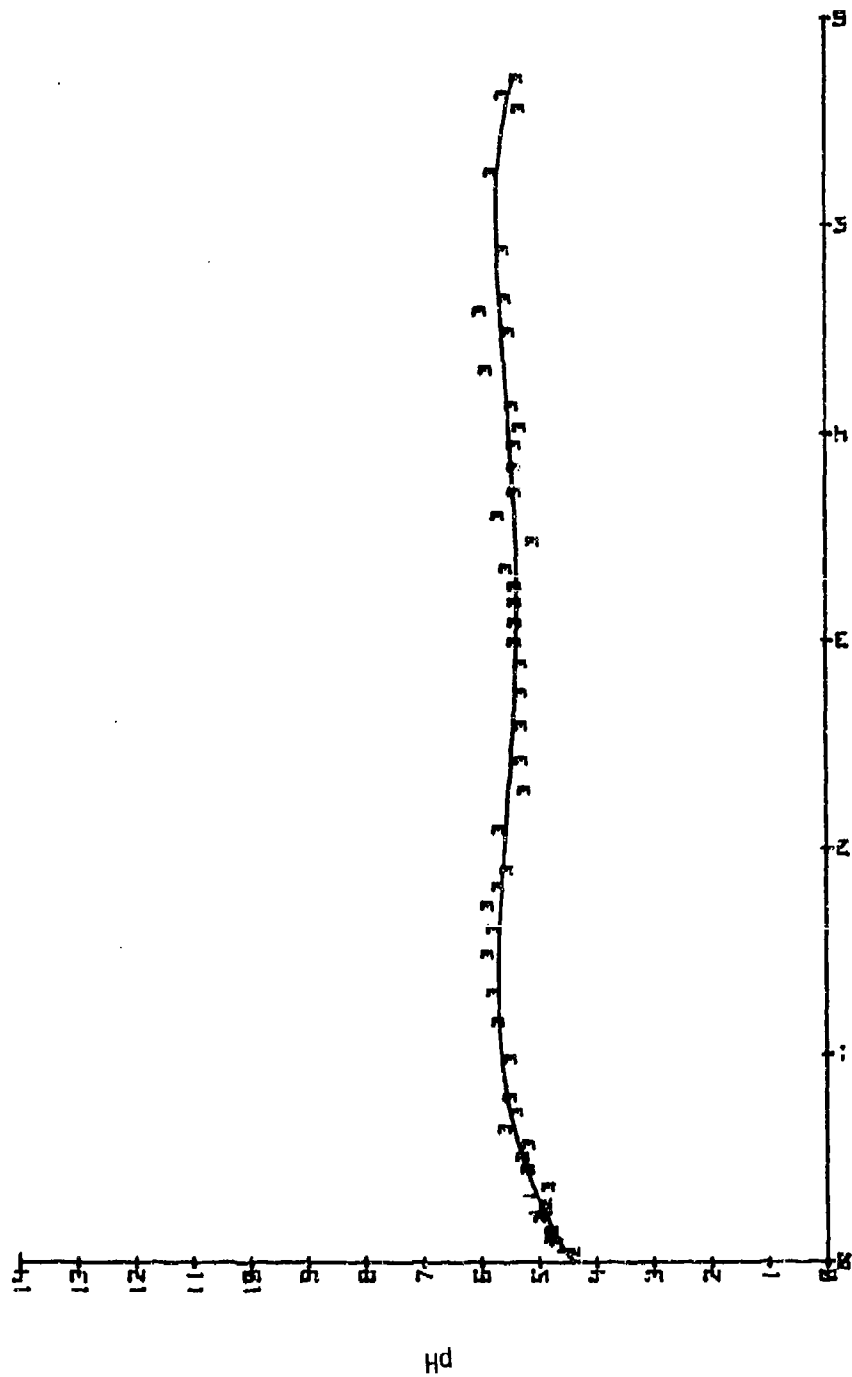


FIGURE 145: CONDUCTANCE OF SOLUTION LEACHED FROM PIGMENT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



CUM VOLUME (ML/GM SOIL)

FIGURE 146: pH OF SOLUTION LEACHED FROM PIGMENT
WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

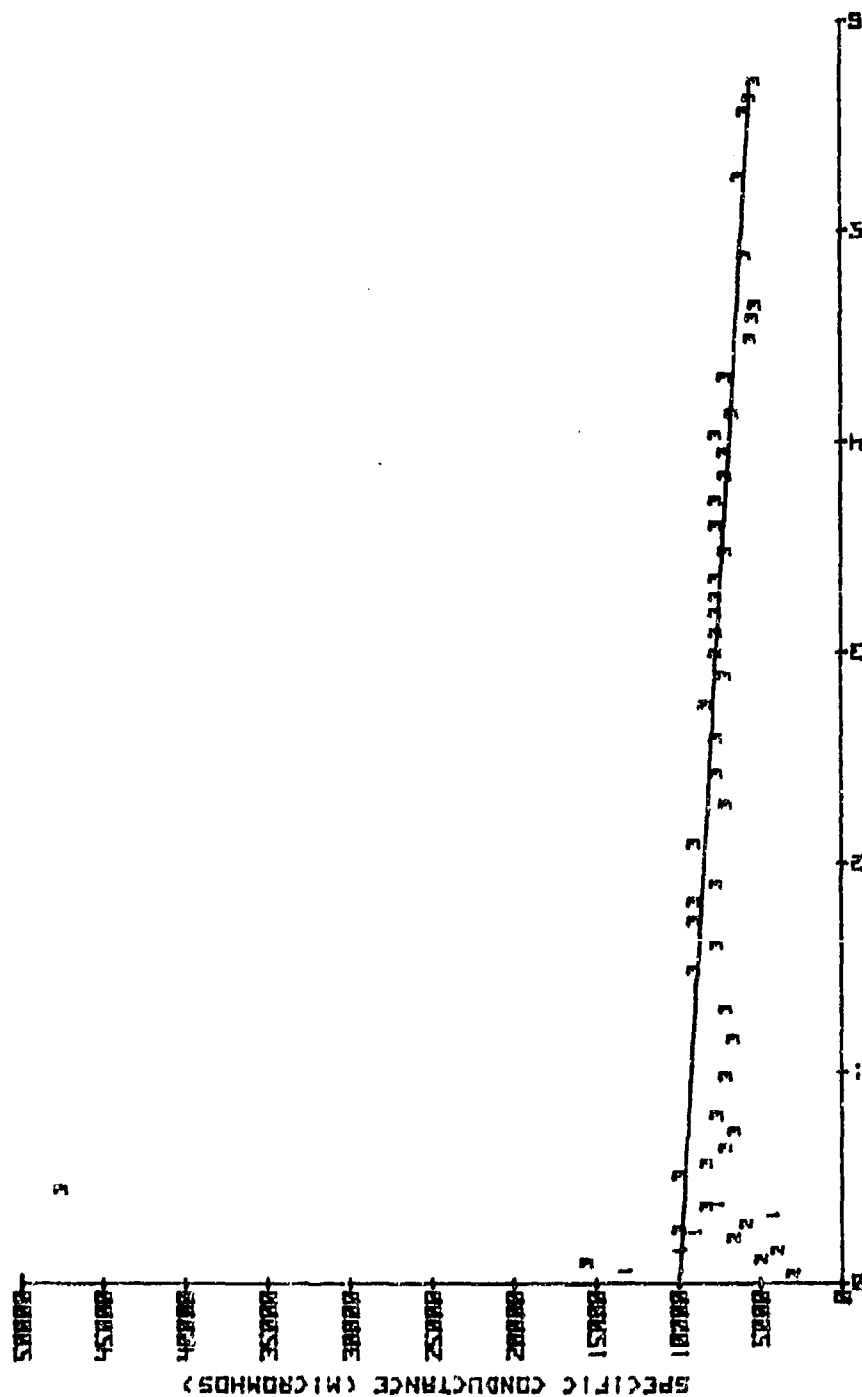
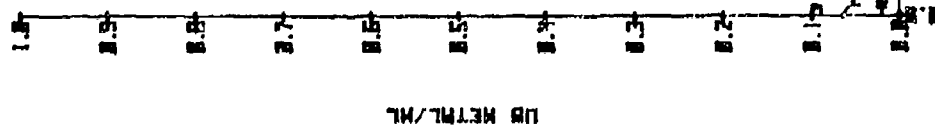


FIGURE 147: CONDUCTANCE OF SOLUTION LEACHED FROM PIGMENT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 8.854538878

COEFF X = -8.841827525

COEFF X² = 8.815388611

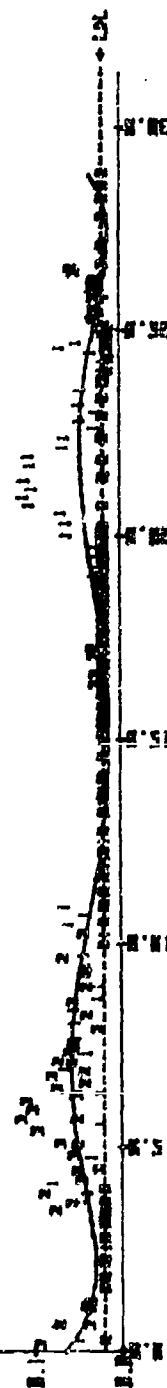
COEFF X³ = -2.422238-03

COEFF X⁴ = 1.515888E-04

COEFF X⁵ = -4.94745E-05

COEFF X⁶ = 5.158888E-08

R² = 8.388713537



CUM VOLUME (ML/G SOIL)

FIGURE 148: CADMIUM LERCHED FROM PRINT WASTE & DAVIDSON SOIL BY WATER

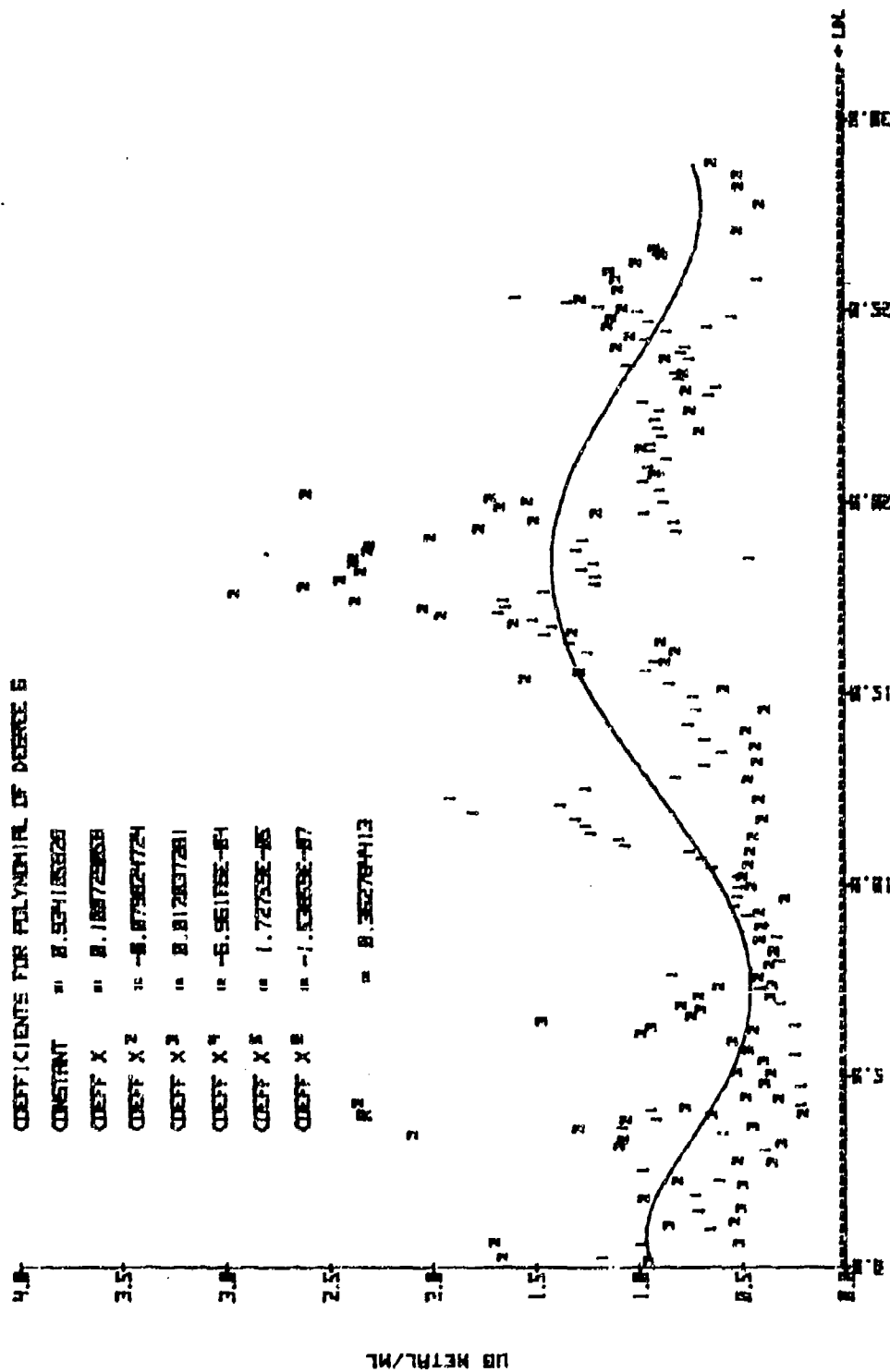


FIGURE 149: ZINC LEACHED FROM PRINT WASTE & DAVIDSON SOIL BY WATER

Figures 150 through 152 are plots of cadmium, nickel and zinc leached by water from water base paint waste and penetrating Kalkaska soil. The concentration of cadmium in the effluents from the Kalkaska soil columns is higher than that found in the Davidson samples. Zinc was found to exceed the standard in only a few samples. Nickel was found in few samples and appeared sporadically.

Attenuation factors could not be calculated for these metals and soils. Although small amounts of cadmium and nickel were detected in the soil column effluents, these concentrations were not sufficiently greater than the concentration in the effluent from the control columns (leached only with water) to indicate conclusively that the metals came from the waste. Zinc was found in higher concentrations in the soil columns effluent than in the waste leachate. This again indicates the ease with which naturally occurring zinc may be leached from the soil.

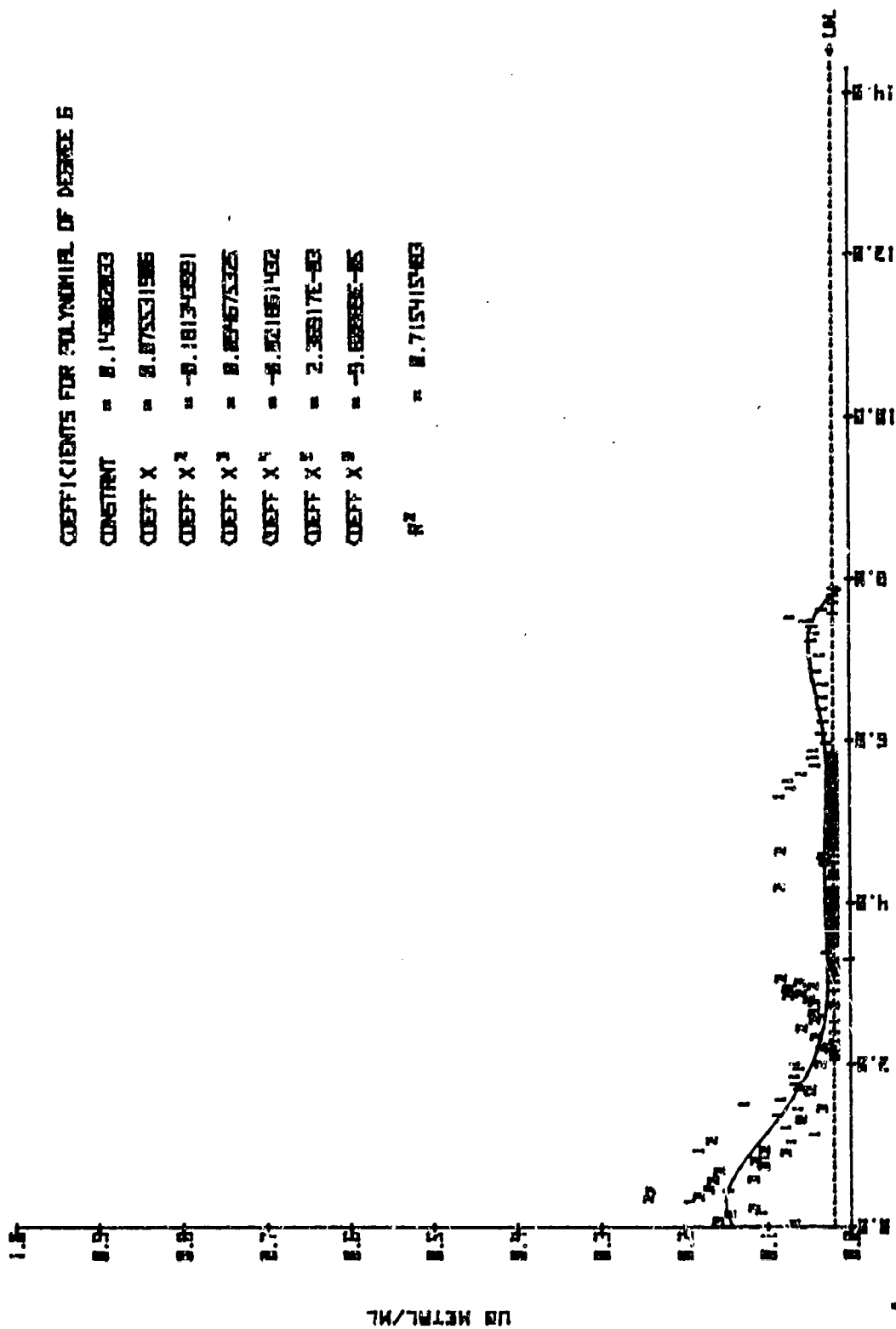
Landfill Leachate Extracts--The amounts of cadmium, copper, lead, nickel, and zinc leached from the water base paint waste by municipal landfill leachate are shown in Figures 53, 55, 56, 58, and 59 (Section 4). Figures 153 through 157 are plots of cadmium, copper, lead, nickel, and zinc leached by municipal landfill leachate from water base paint waste and penetrating Davidson soil. Zinc, because of its high concentration in the soil samples, was most abundant in the leachate. Cadmium was found initially in high concentrations. Lead also exceeded the water standard. Nickel and copper were present at low concentrations.

Figures 158 through 164 are plots of cadmium, chromium, copper, mercury, lead, nickel and zinc leached by municipal landfill leachate from water base paint waste and penetrating Kalkaska soil. Zinc was found in the soil in very high concentrations. Cadmium was also found at many times above the drinking water standard. Chromium, lead and mercury levels exceeded the water standard while copper and nickel did not.

This data suggests that, as for the other wastes, the probability of solubilized metals and/or salts extracted from the waste reaching ground water would be greatly increased if this waste were placed in contact with municipal refuse or placed so the leachate from municipal refuse could contact it. Certainly, if co-disposal of this waste with municipal refuse is practiced, it should be very carefully managed.

Figure 165 shows the fraction of each metal, from the municipal landfill leachate leaching of the water base paint waste, that passes through each soil.

pH and Conductance Measurements--Figures 166 through 173 are plots of the pH and specific conductance values obtained from the soil column effluent samples when water and municipal landfill leachate were used as the leaching solvents. The pH values of the Davidson waste treated soil



CHROMIUM (MG/L)

FIGURE 150: CHROMIUM LEACHED FROM PRINT WASTE & KALKASKA SOIL BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.143862633

COEFF X = 0.875531986

COEFF X² = -0.181343221

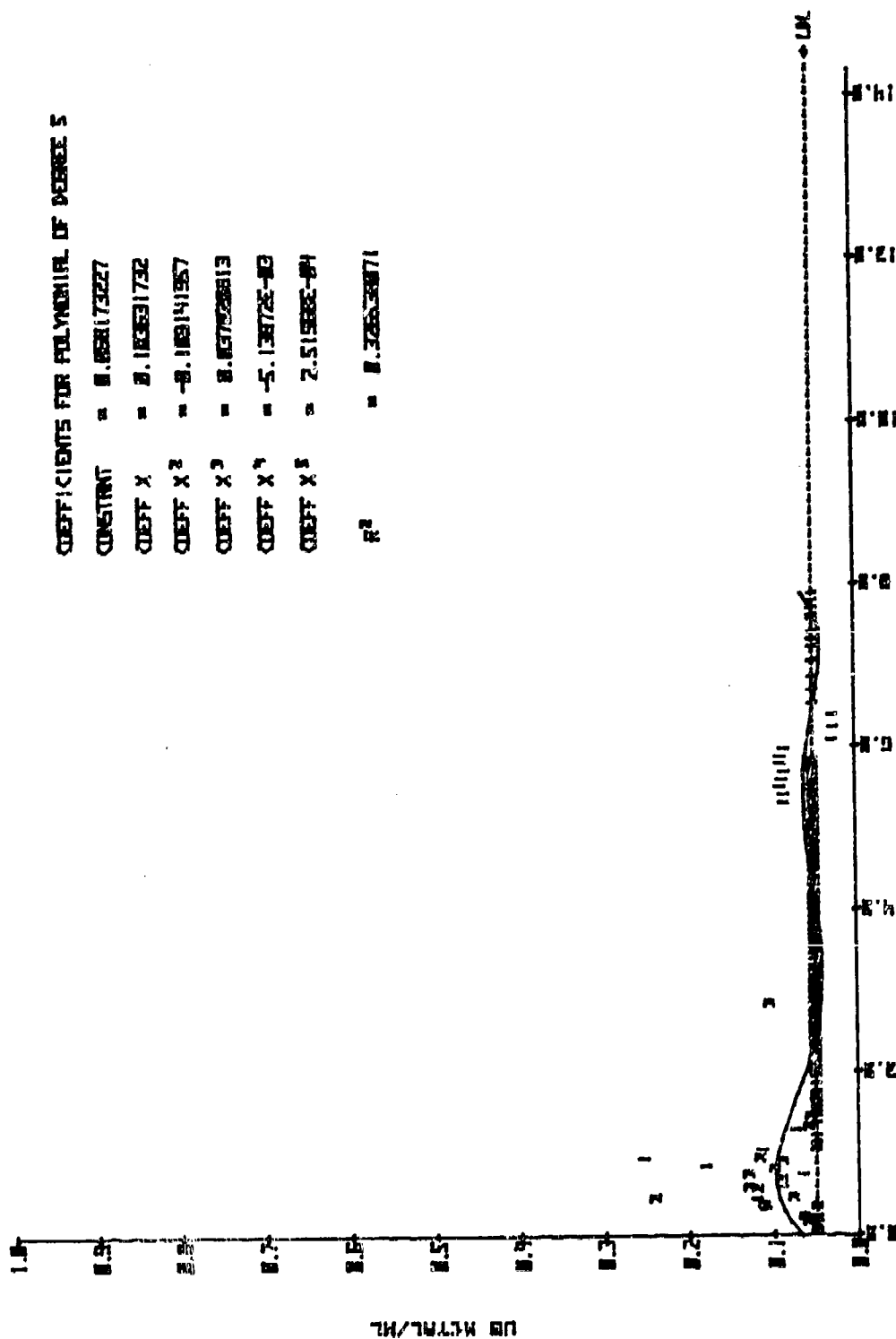
COEFF X³ = 0.034675325

COEFF X⁴ = -0.021861492

COEFF X⁵ = 2.36317E-03

COEFF X⁶ = -9.03333E-05

R² = 0.715415483



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.000173227

COEFF X = 0.00031732

COEFF X² = -0.000141557

COEFF X³ = 0.000023313

COEFF X⁴ = -5.13872E-03

COEFF X⁵ = 2.51588E-04

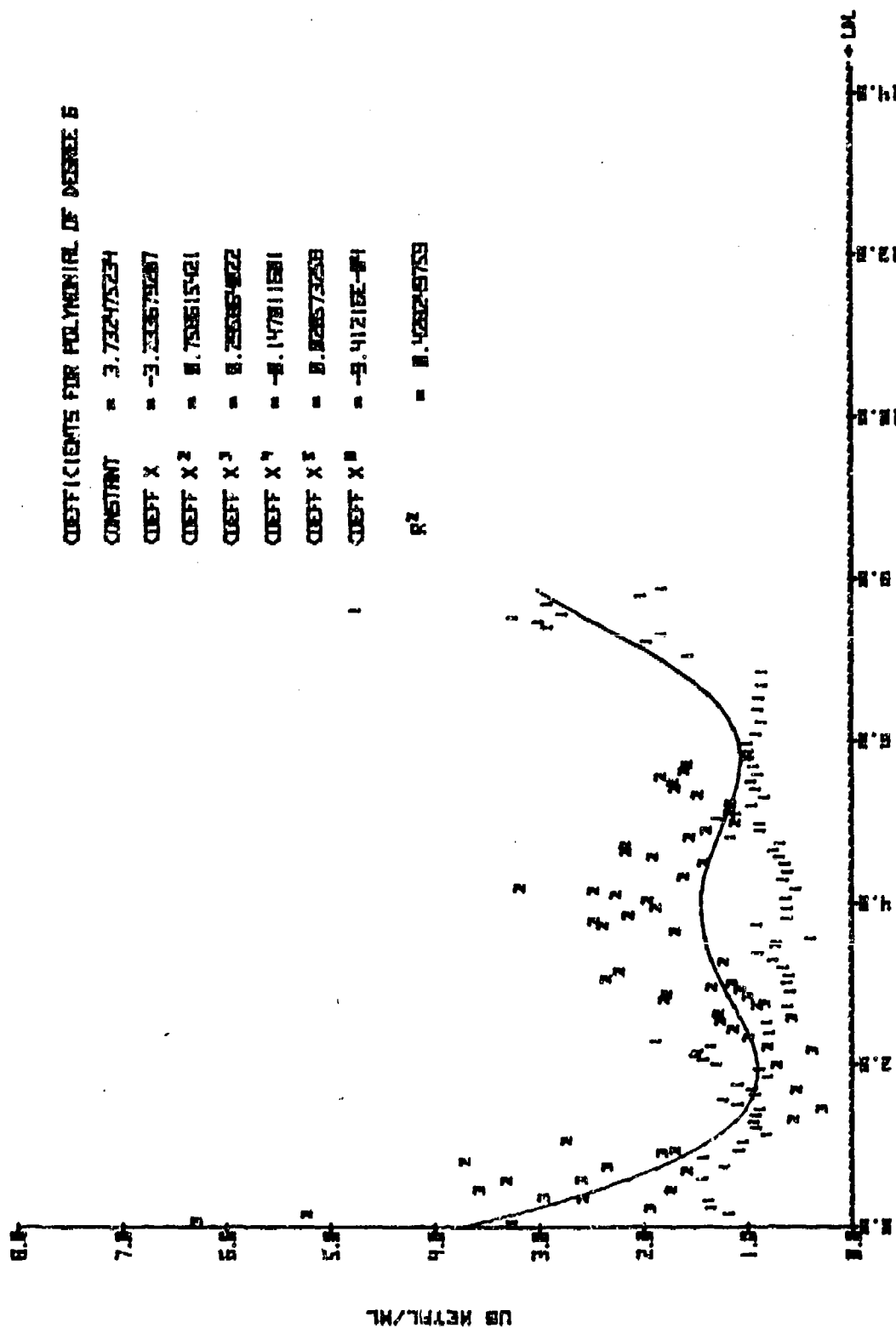
R² = 0.32633871

CUM VOLUME (ML/G SOIL)

FIGURE 151: NICKEL LEACHED FROM PRINT WASTE & KALKREUTH SOIL BY WATER

COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 3.732475234
 COEFF X = -3.233679287
 COEFF X² = 0.758615421
 COEFF X³ = 0.256854022
 COEFF X⁴ = -0.147811801
 COEFF X⁵ = 0.026573253
 COEFF X⁶ = -0.412162-074
 R² = 0.428245759



CM VOLUME (ML/CM SOIL)

FIGURE 152: ZINC LEACHED FROM PRINT WASTE & KALKASKA SOIL BY WATER

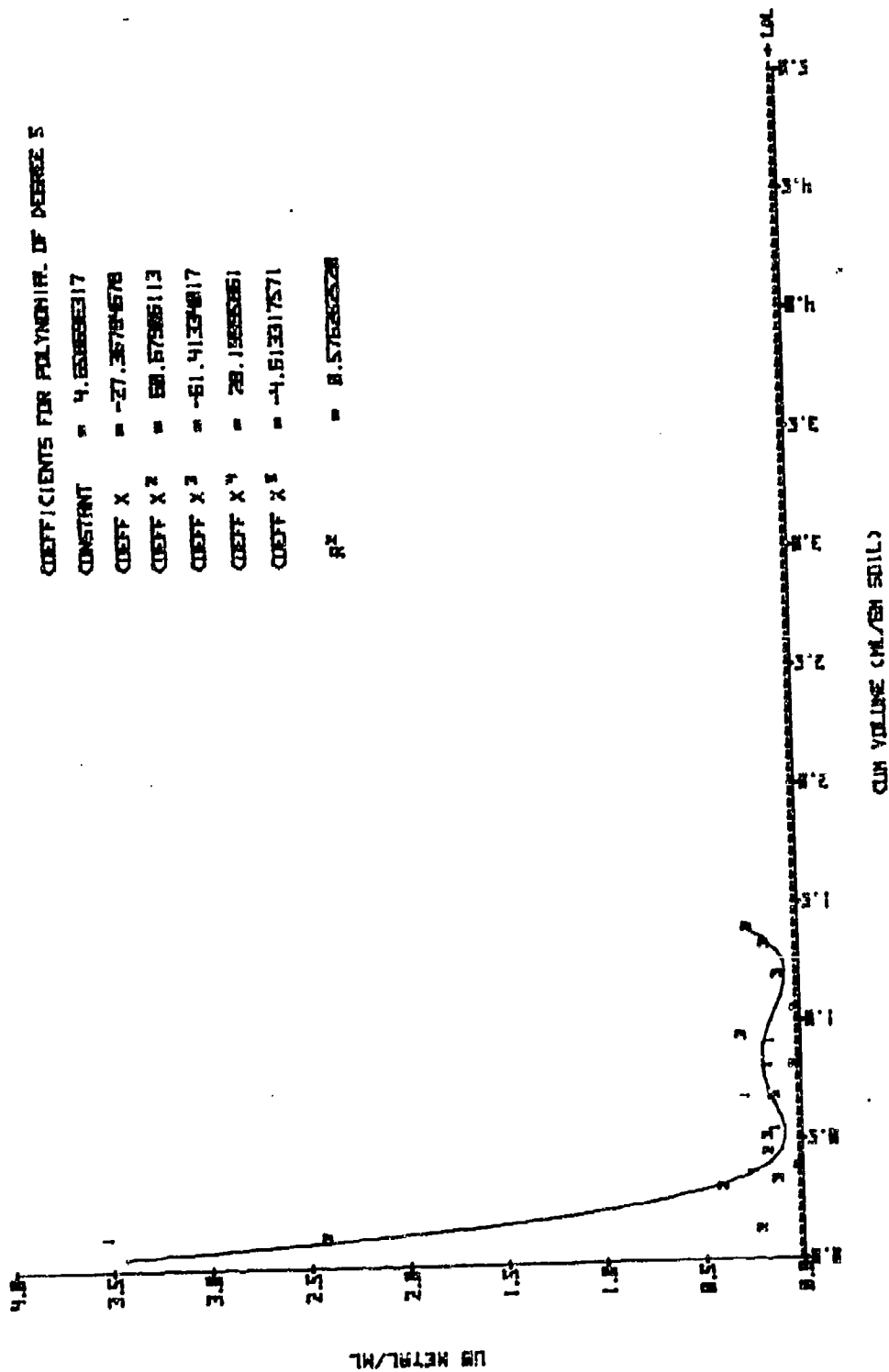
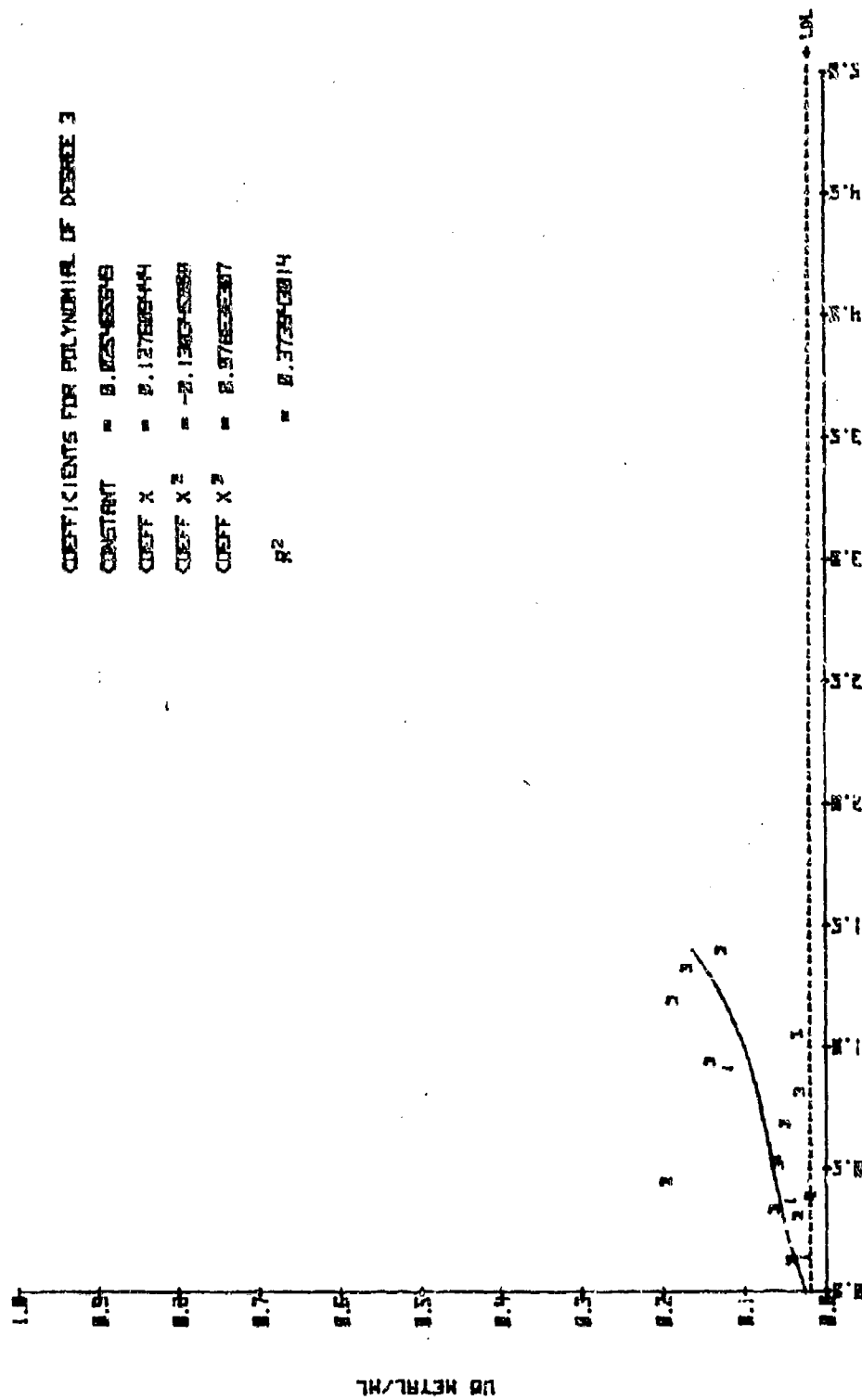


FIGURE 153: CADMIUM LEACHED FROM PAINT WASTE & DRYDOWN SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 3

CONSTANT = 0.025465348

COEFF X = 0.127608444

COEFF X² = -2.136345288

COEFF X³ = 0.976633307

R² = 0.973943814

CUM VOLUME (ML/GB SOIL)

FIGURE 154 : COPPER LEACHED FROM PAINT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

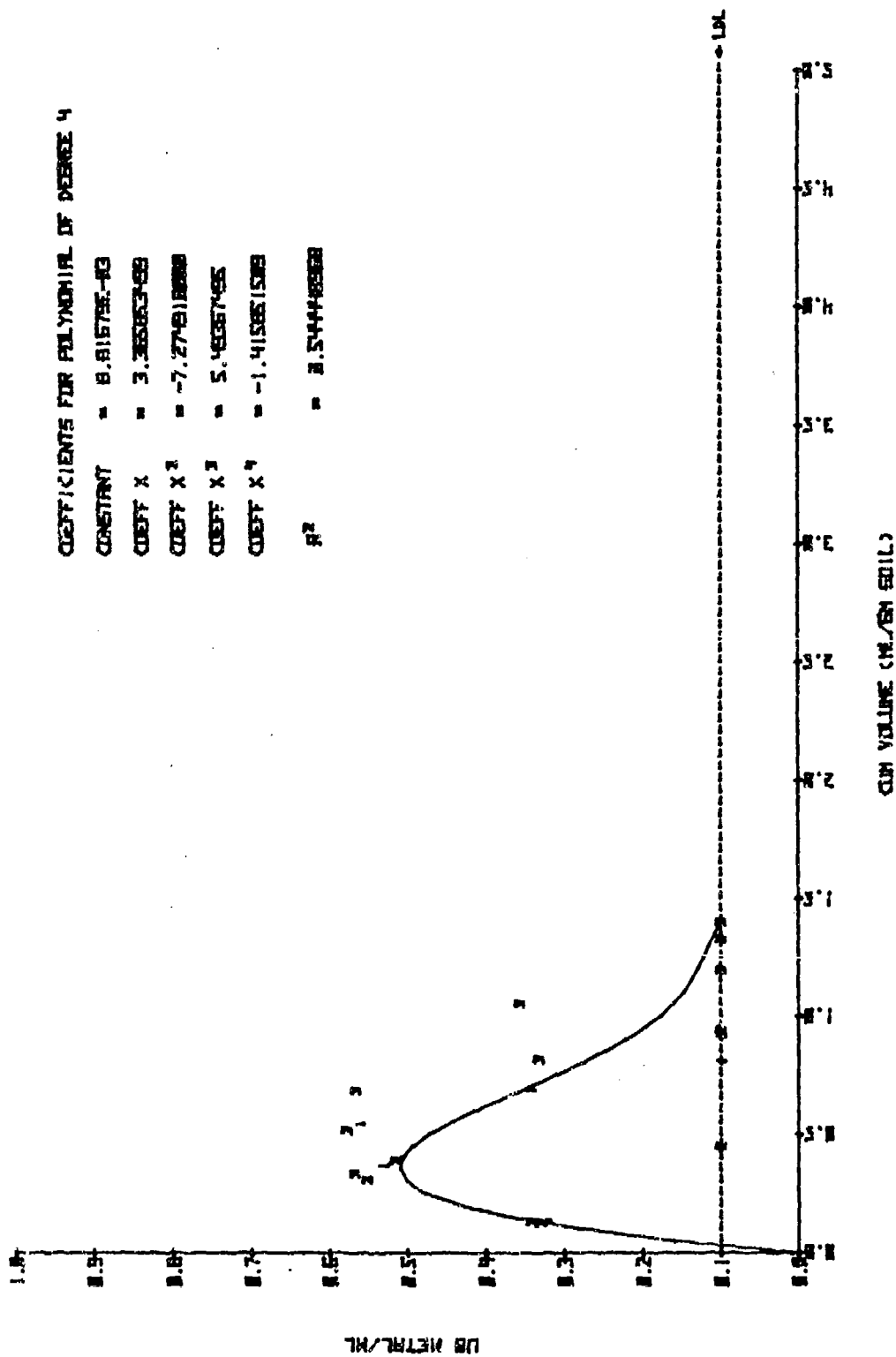
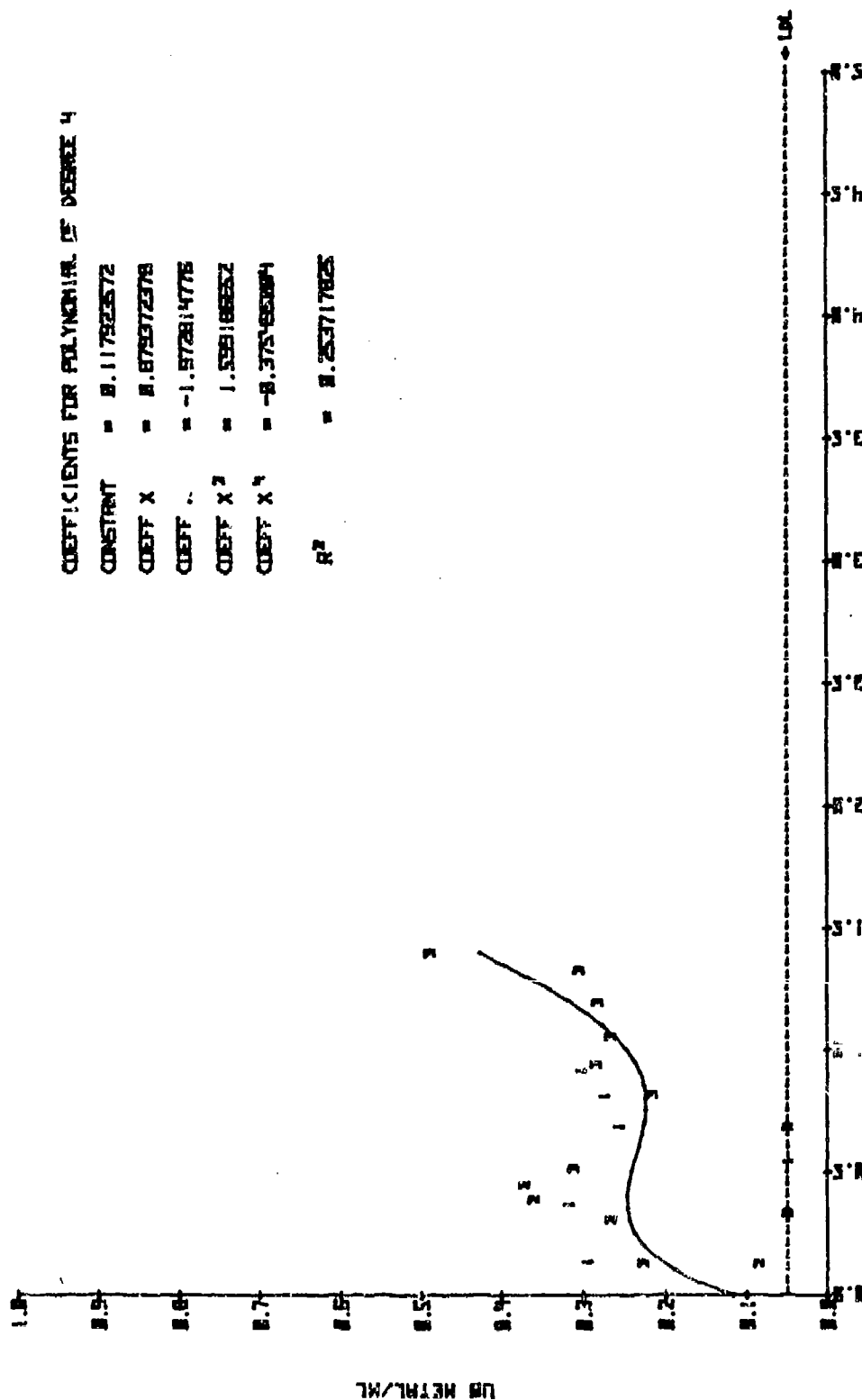


FIGURE 155: LEAD LEACHED FROM PRINT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 4

CONSTANT = 0.117923572

COEFF X = 0.879372378

COEFF X² = -1.572814775

COEFF X³ = 1.538188552

COEFF X⁴ = -0.375483084

R² = 0.253717825

CUM VOLUME (ML/BA SOIL)

FIGURE 156: NICKEL LEACHED FROM PAINT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

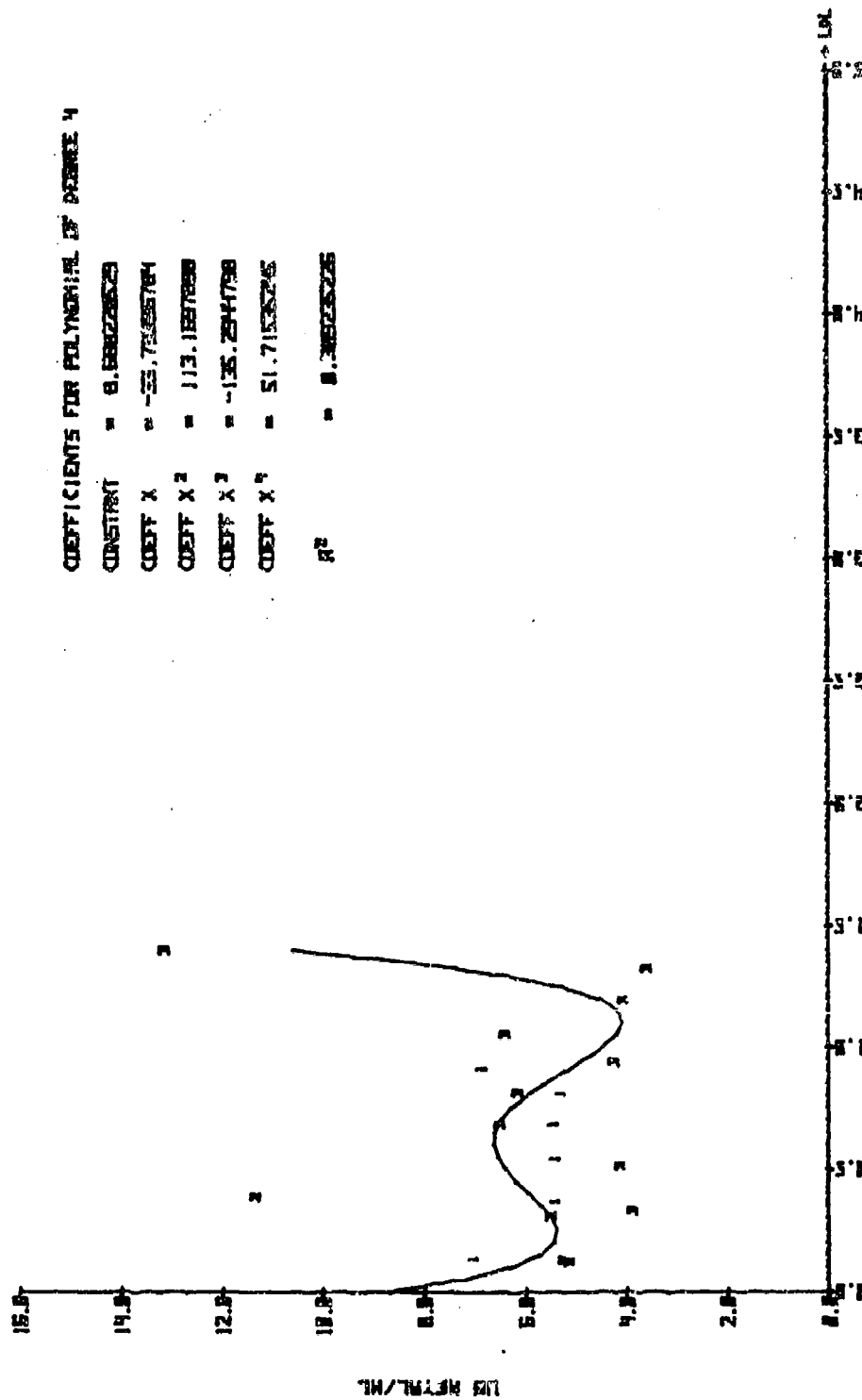
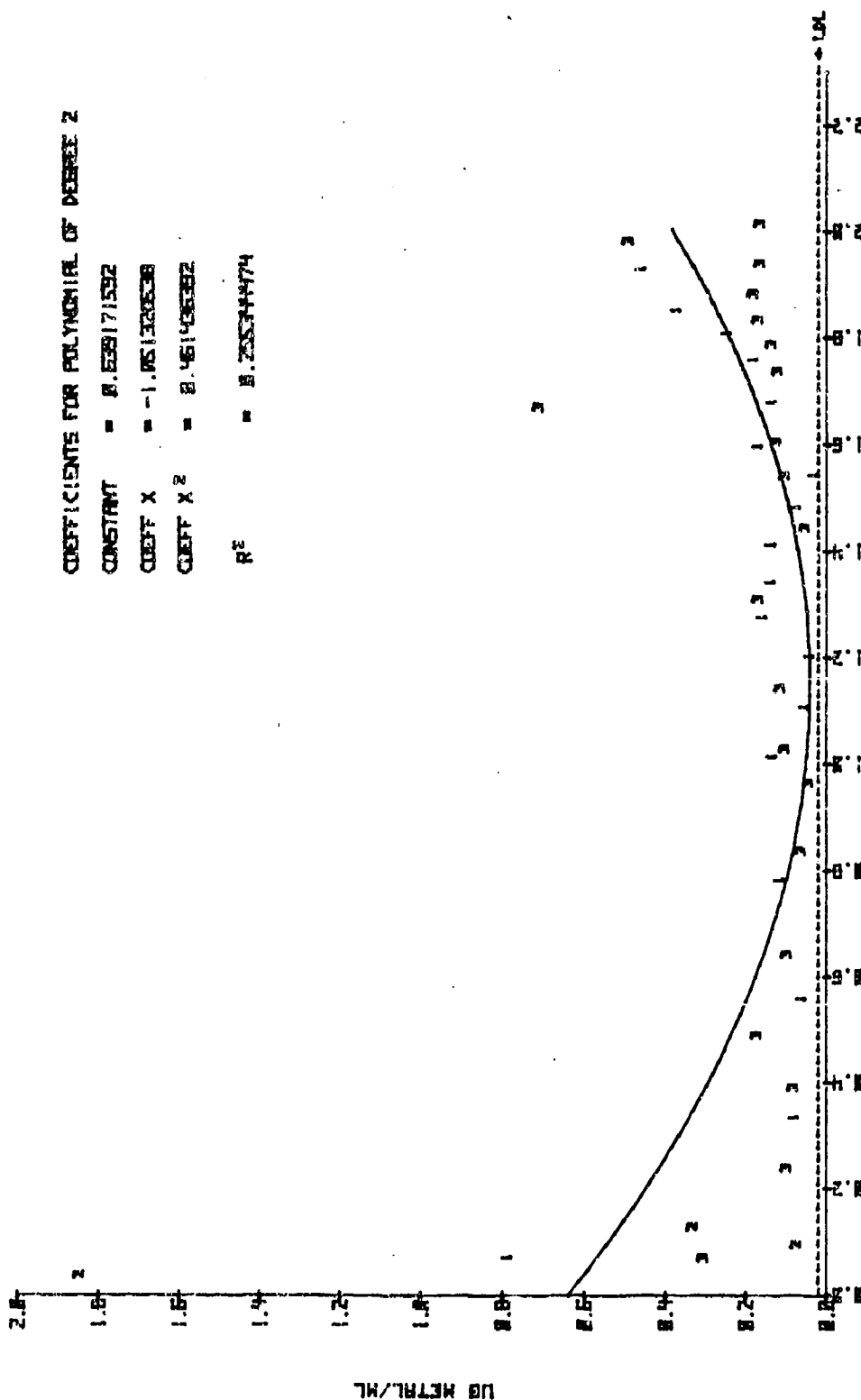


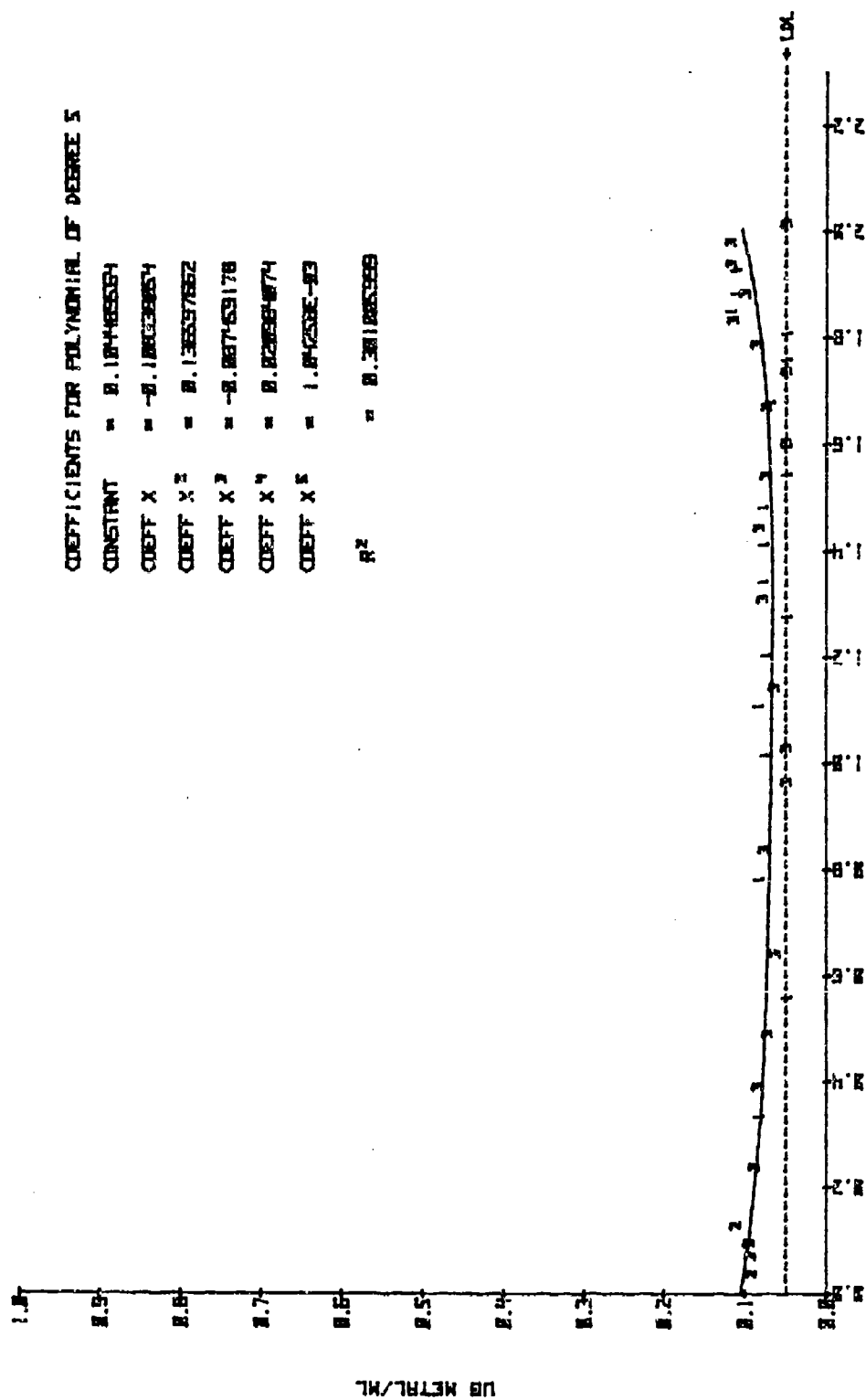
FIGURE 157: ZINC LEACHED FROM PAINT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 2
 CONSTANT = 0.000171592
 COEFF X = -1.051300000
 COEFF X² = 0.000000000
 R² = 0.255344474

CUM VOLUME (ML/GN SOIL)

FIGURE 158: CADMIUM LEACHED FROM PAINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.104465324

COEFF X = -0.100338554

COEFF X² = 0.13657662

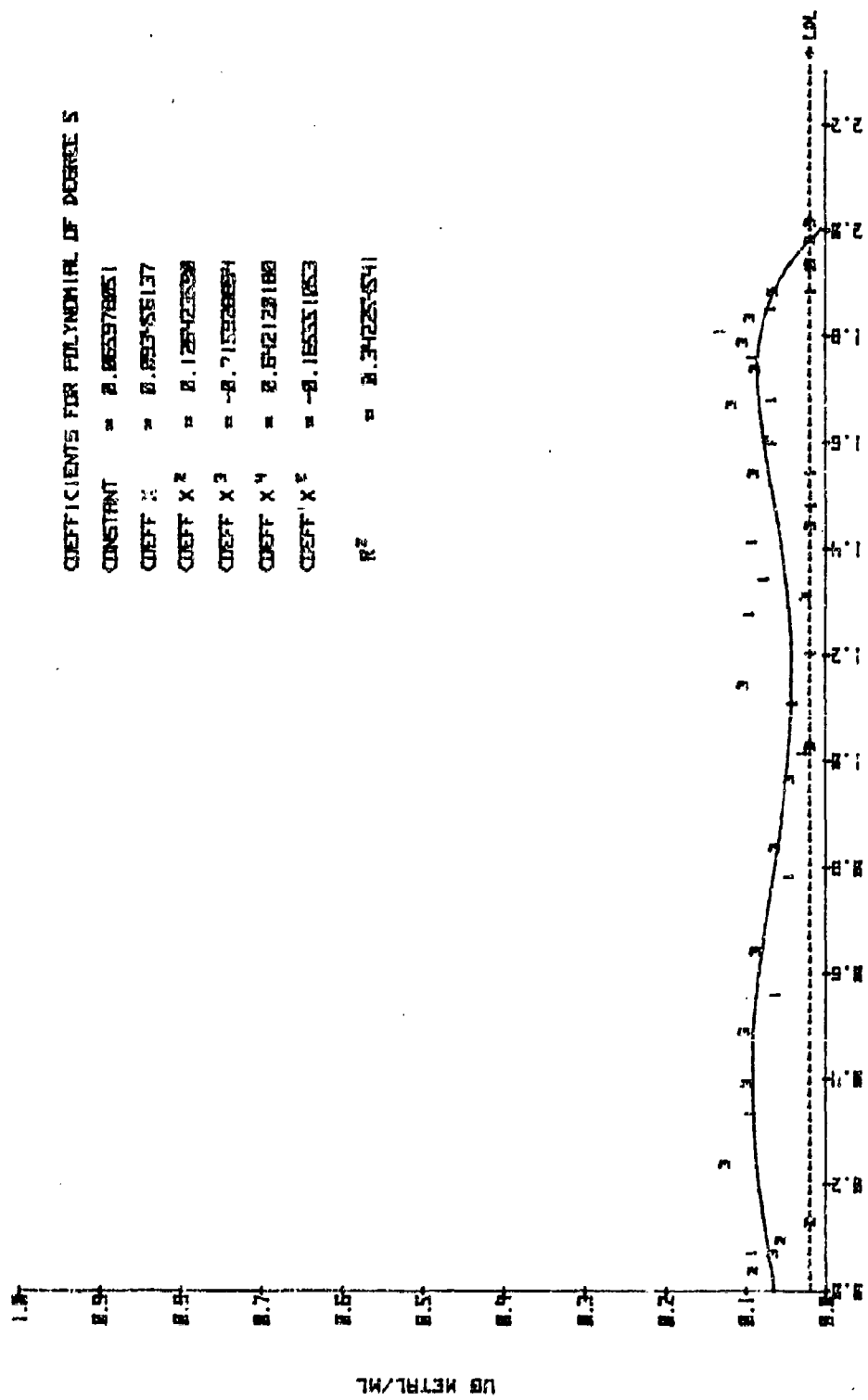
COEFF X³ = -0.007459178

COEFF X⁴ = 0.020384074

COEFF X⁵ = 1.04253E-03

R² = 0.381085359

FIGURE 159: CHROMIUM LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

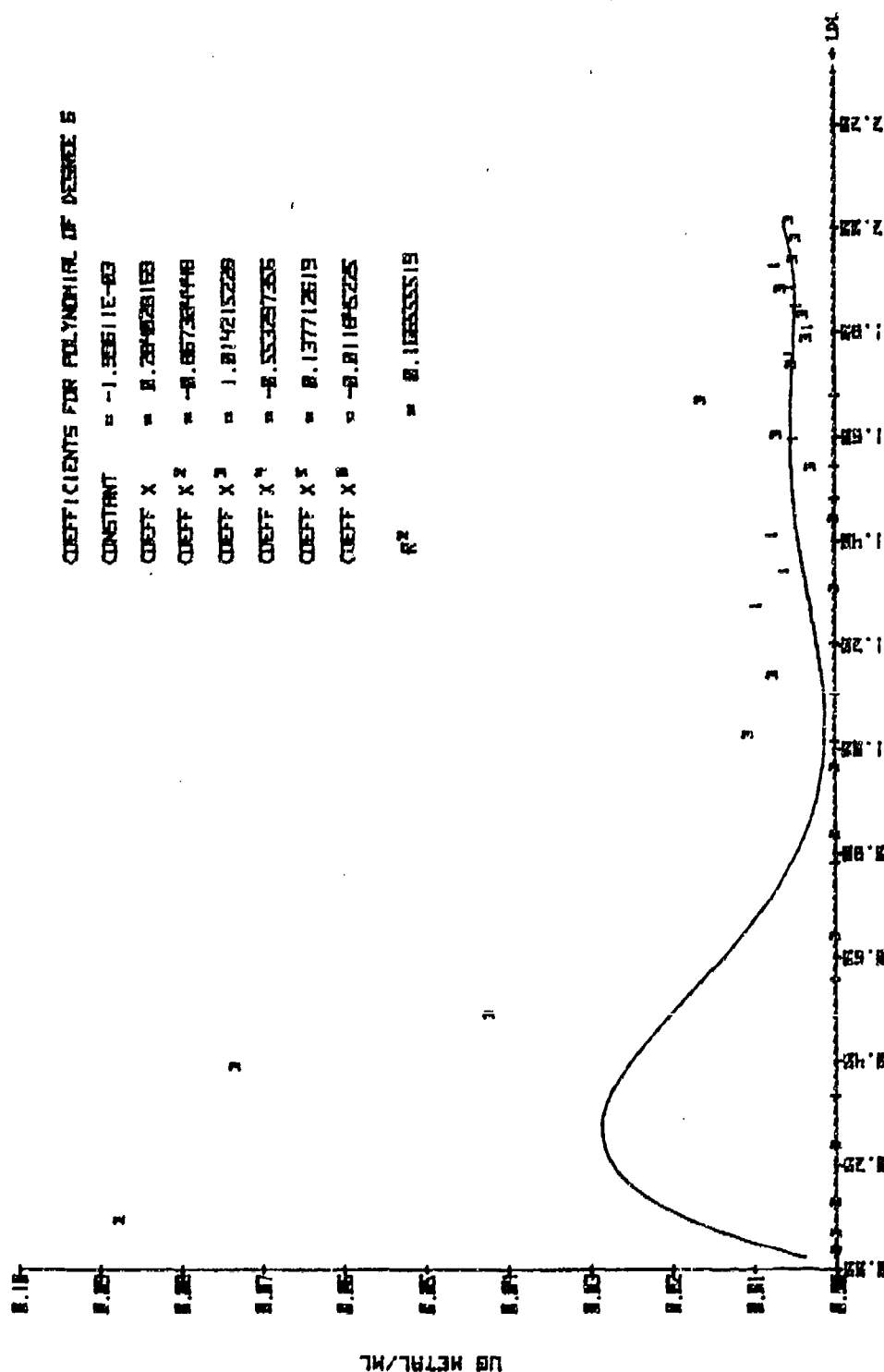


COEFFICIENTS FOR POLYNOMIAL OF DEGREE 5

CONSTANT = 0.065978051
 COEFF X = 0.093456137
 COEFF X² = 0.12842839
 COEFF X³ = -0.715328854
 COEFF X⁴ = 0.642128180
 COEFF X⁵ = -0.16331053
 R² = 0.34254541

CuM VOLUME (ML/GH SOIL)

FIGURE 160: COPPER LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



MIN VOLUME (ML/200 ML SOIL)

FIGURE 16: MERCURY LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

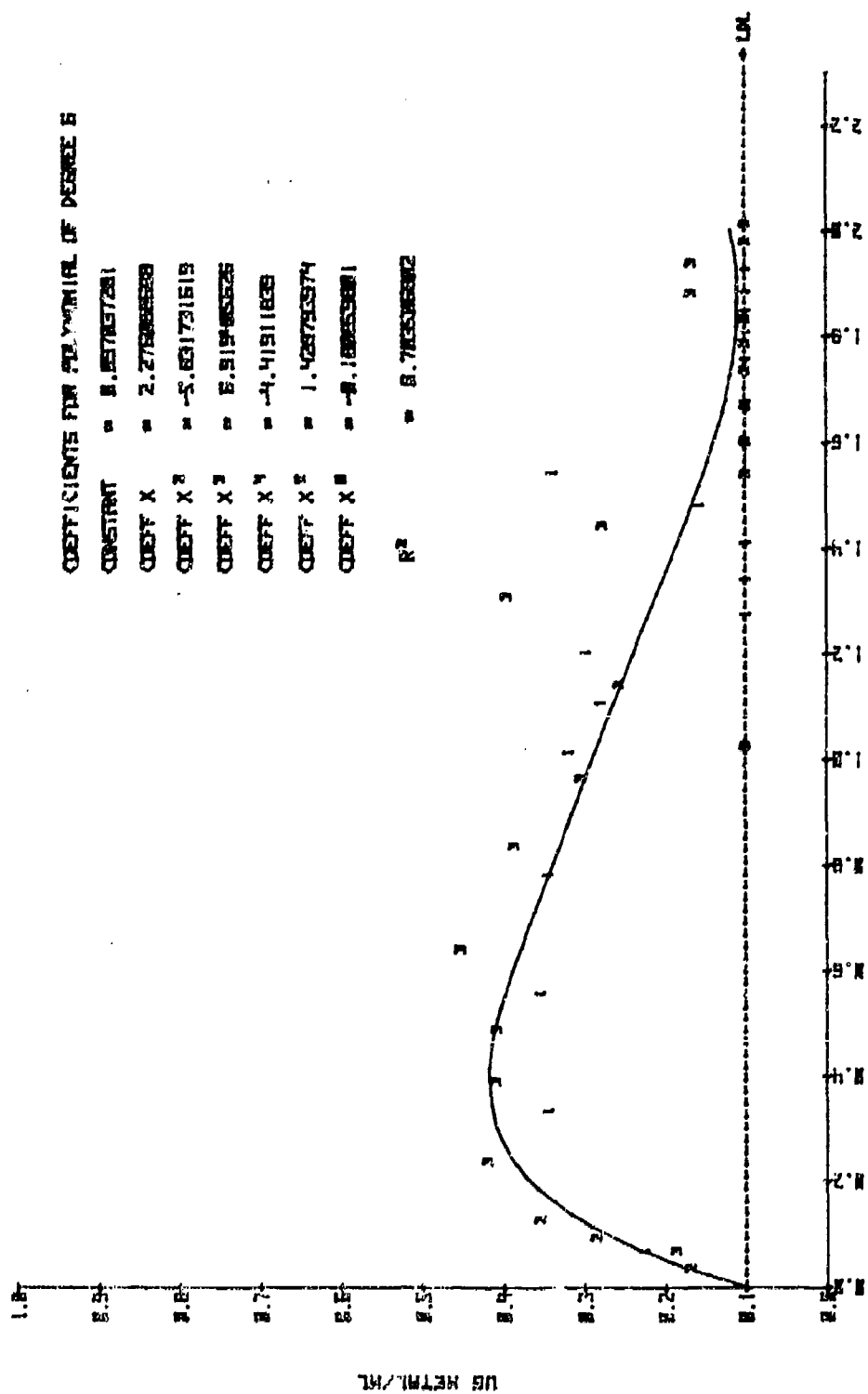


FIGURE 162: LEAD LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LERCHATE

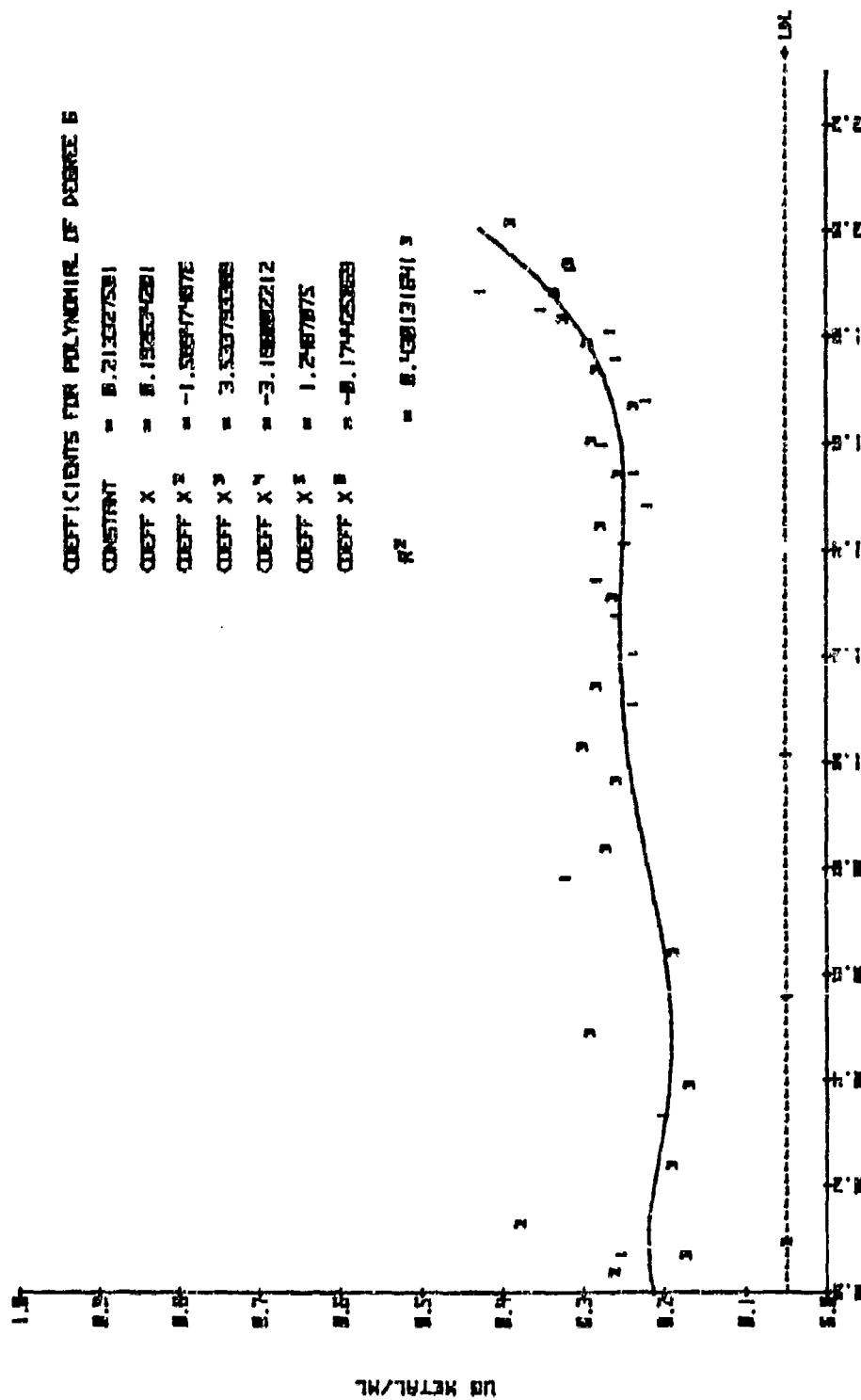
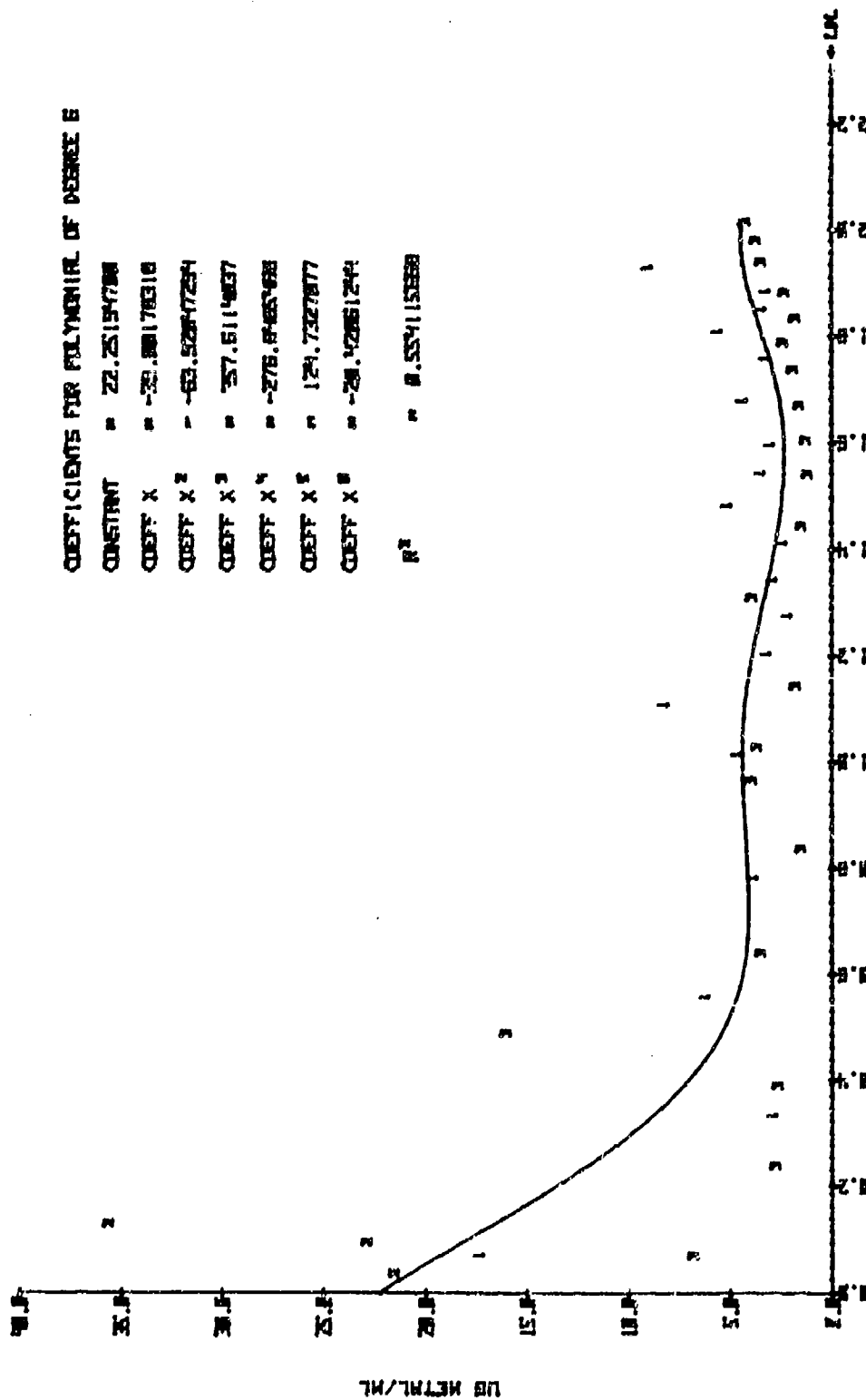


FIGURE 163: NICKEL LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



COEFFICIENTS FOR POLYNOMIAL OF DEGREE 6

CONSTANT = 22.25154708

COEFF X = -32.88178318

COEFF X² = -63.52847254

COEFF X³ = 57.6114837

COEFF X⁴ = -276.8485488

COEFF X⁵ = 124.7327877

COEFF X⁶ = -28.12861244

R² = 0.554115338

CUM VOLUME (ML/GN SOIL)

FIGURE 164: ZINC LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LERCHSTE

samples were very similar to the pH values obtained from the control columns leached with distilled water.

The conductance values in the soil column effluents from both Davidson and Kalkaska soils were initially much higher than the conductance of effluents from the control columns receiving only distilled water. As the conductance of the waste leachate going into the soil decreased, the conductance of the soil column effluents also decreased rapidly.

The pH values in the effluent from the Davidson soil-waste columns leached with municipal landfill leachate were slightly more basic than were the control column values. The Kalkaska pH values from the waste treated columns and the control columns were nearly the same, indicating that the Kalkaska was more strongly buffered at its natural pH than was the Davidson. The conductance values of both soils treated with wastes were similar to the control column results. The conductance value did not decrease as the leaching continued as was observed when water was used as the leaching solvent but increased, as did the control columns.

Chlorine Production Brine Waste--

Mercury was not found in the chlorine production brine waste samples when leached with water. A small amount was found when the waste was leached with municipal landfill leachate. Some may have been present in municipal landfill leachate. However, it is felt that most was leached from the waste and the soil. Figures 174 and 175 are plots of mercury leached from the waste and penetrating Davidson and Kalkaska soils. A small amount of mercury penetrated Davidson immediately but dropped below detection limits after a cumulative volume of 2 milliliters/gram of soil (320 milliliters) had passed through the column. The level of mercury was very low but exceeded the drinking water standard. Mercury penetrated the Kalkaska soil at nearly a constant level throughout the leaching period.

This suggests that disposal of this waste will be a problem only when there is likely to be contact with municipal landfill leachate. It should be noted that recent information indicates that the mercury contained in and released from this waste is much lower than for wastes from other sources of chlorine brine wastes (20). This is likely due to the advanced housekeeping and waste treatment procedures employed at the plant where the waste for this study was collected. The results could have been quite different if resources had been available to study a number of samples of this waste from different sources.

Figures 176 through 179 are pH and specific conductance plots. The pHs of the effluents from the waste-treated Davidson soil samples were more alkaline than the Davidson control samples. The Kalkaska samples were quite close to the control samples. The conductance values of the samples were extremely high showing the solubility of the wastes in municipal landfill leachate.

D= DAVIDSON

K= KALKASKA

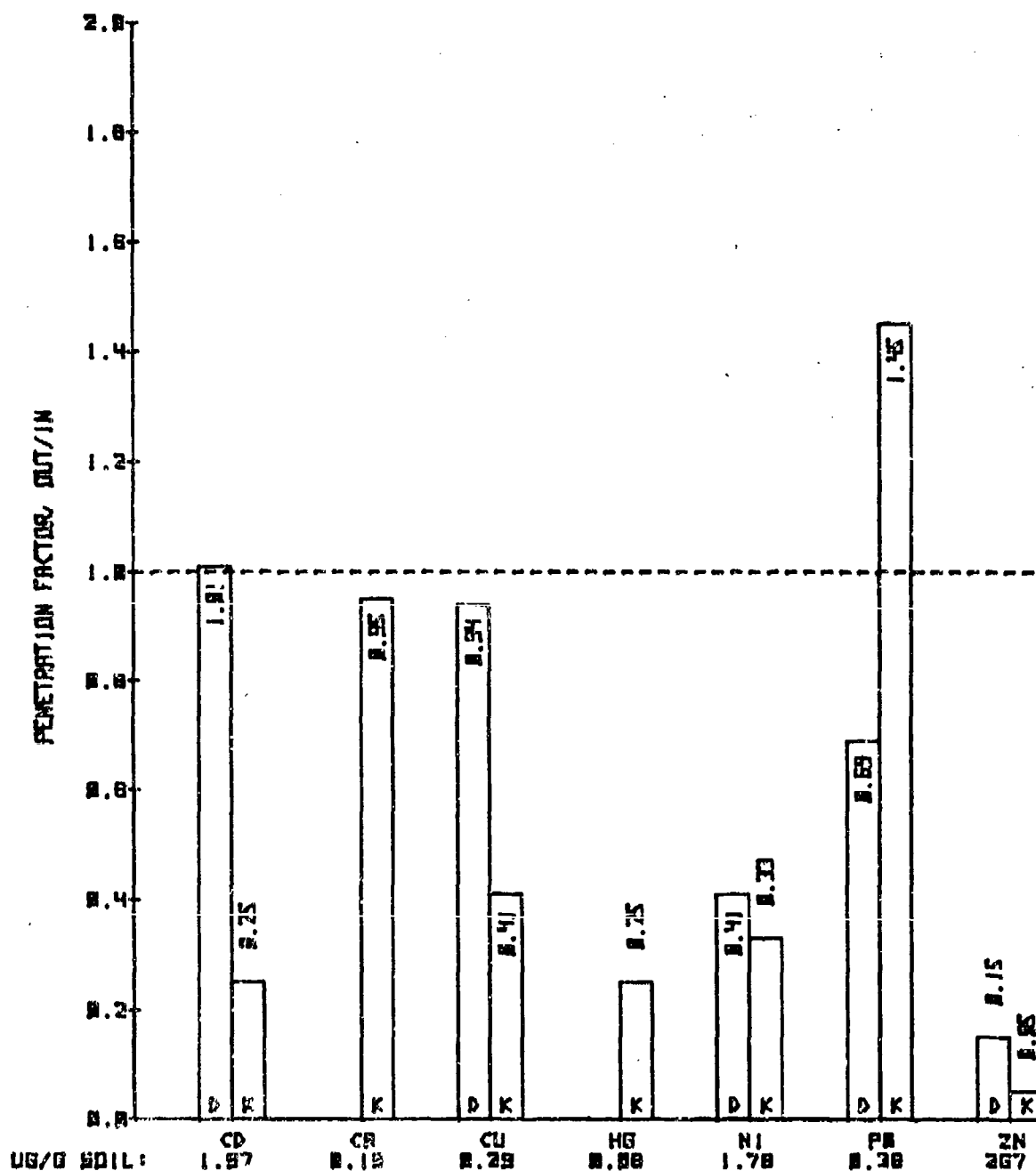


FIGURE 185: METALS IN SOIL COLUMN EFFLUENTS (OUT) AS A FRACTION OF METAL APPLIED (IN) FROM A LANDFILL LEACHATE EXTRACT OF PAINT WASTE

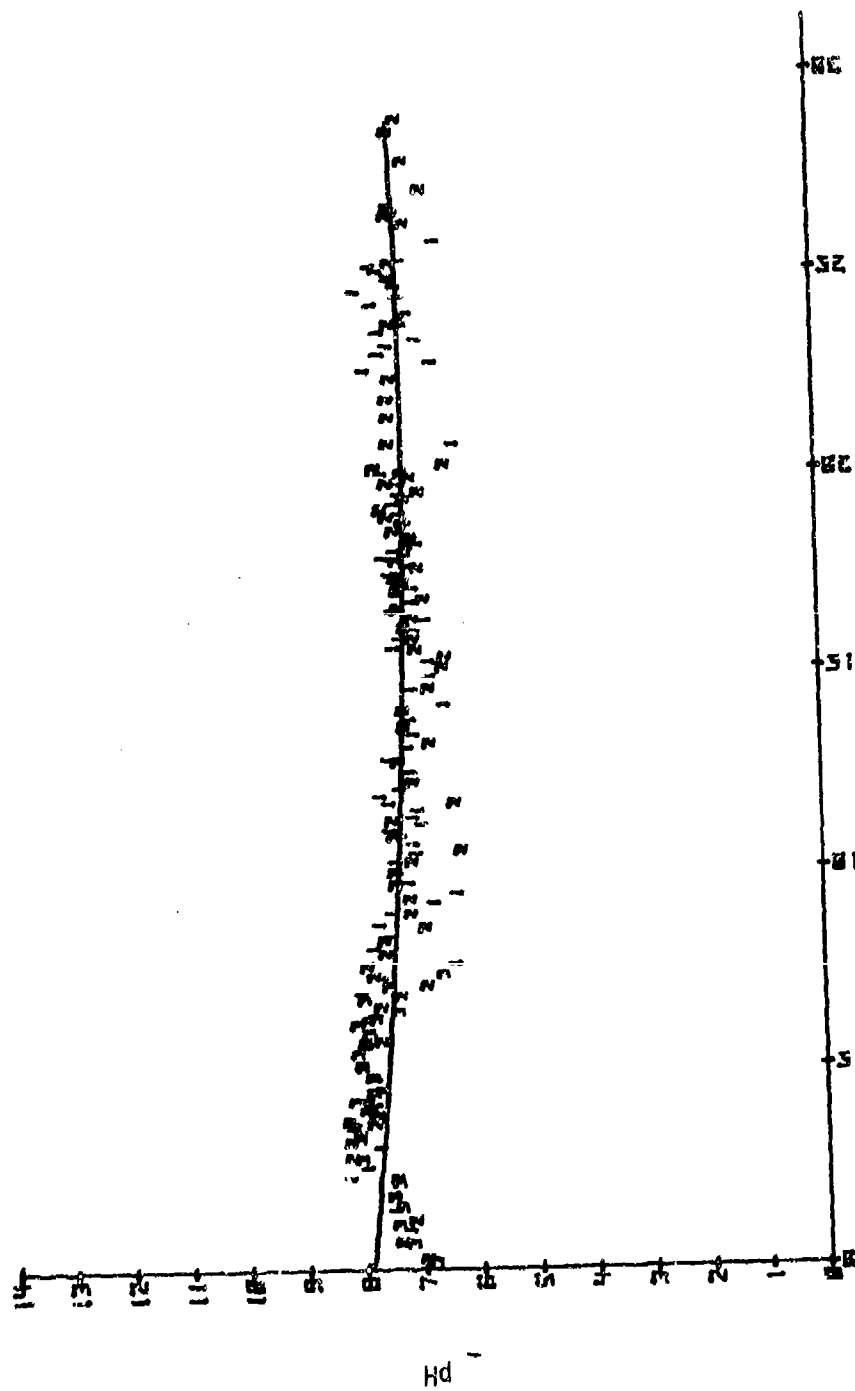


FIGURE 165: pH OF SOLUTION LEACHED FROM PRINT WASTE & DAVIDSON SOIL BY WATER

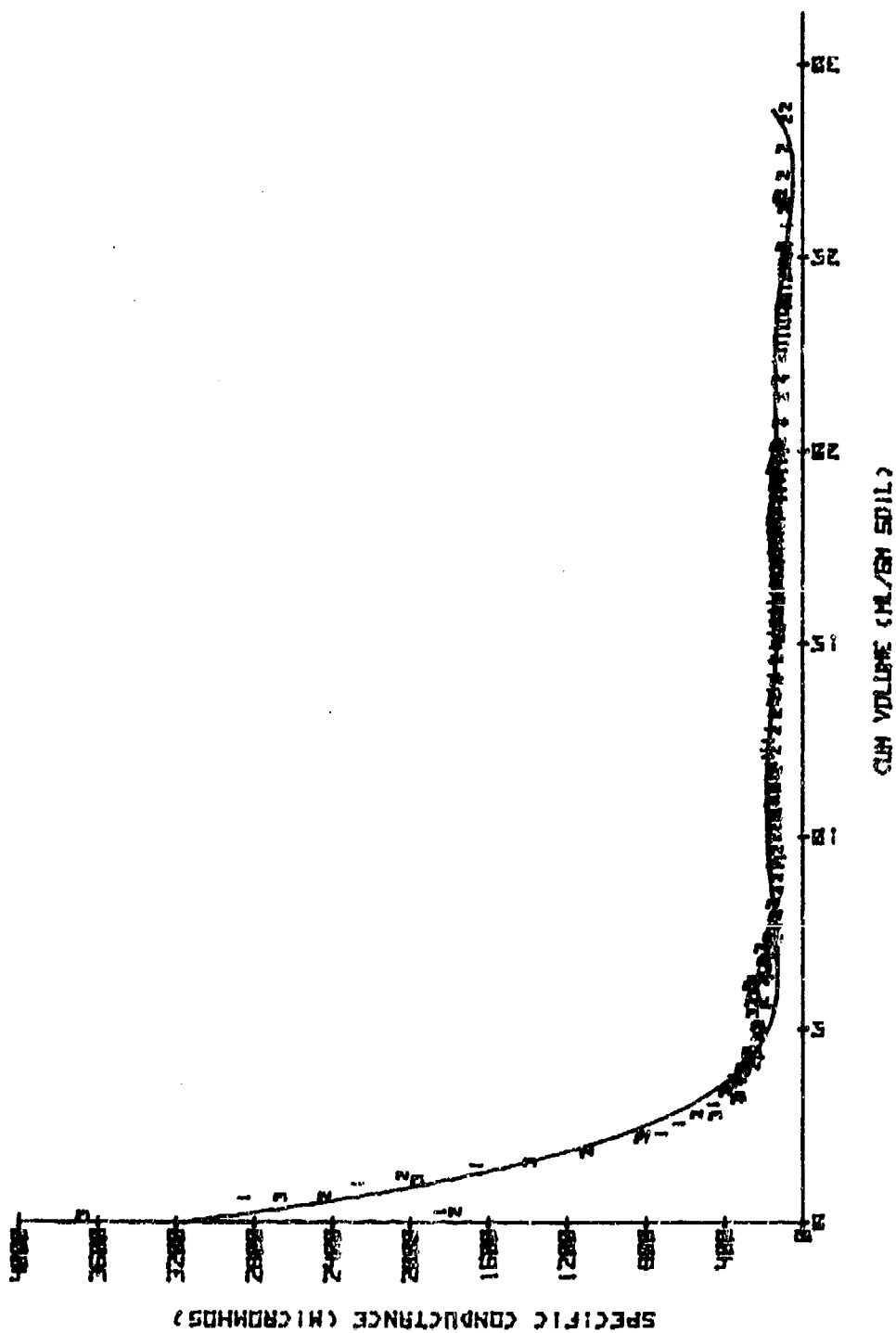
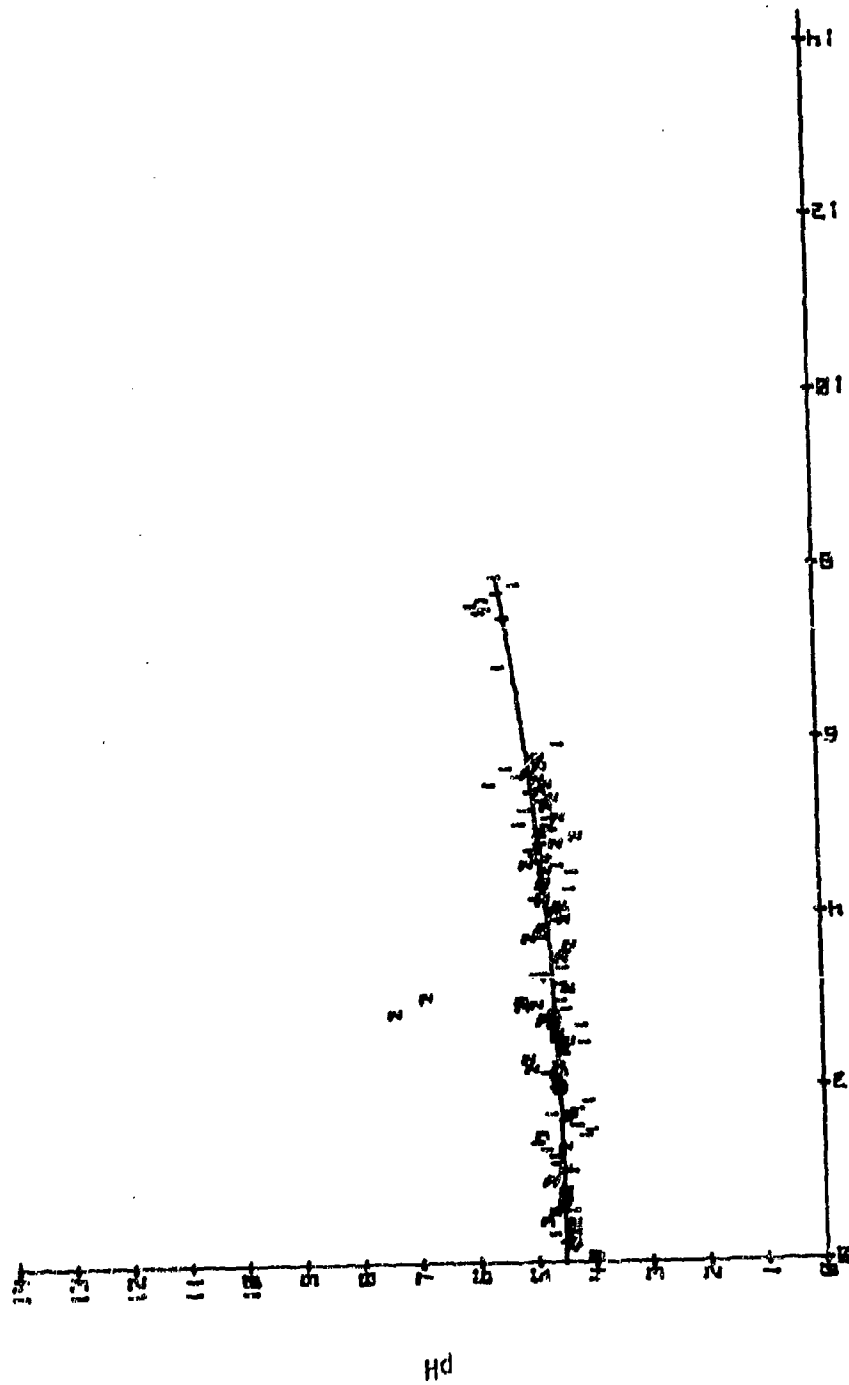


FIGURE 167: CONDUCTANCE OF SOLUTION LEACHED FROM PAINT - WASTE & DAVIDSON SOIL BY WATER



CUM VOLUME (ML/GM SOIL)

FIGURE 168: pH OF SOLUTION LEACHED FROM PAINT WASTE & KALKASKA SOIL BY WATER

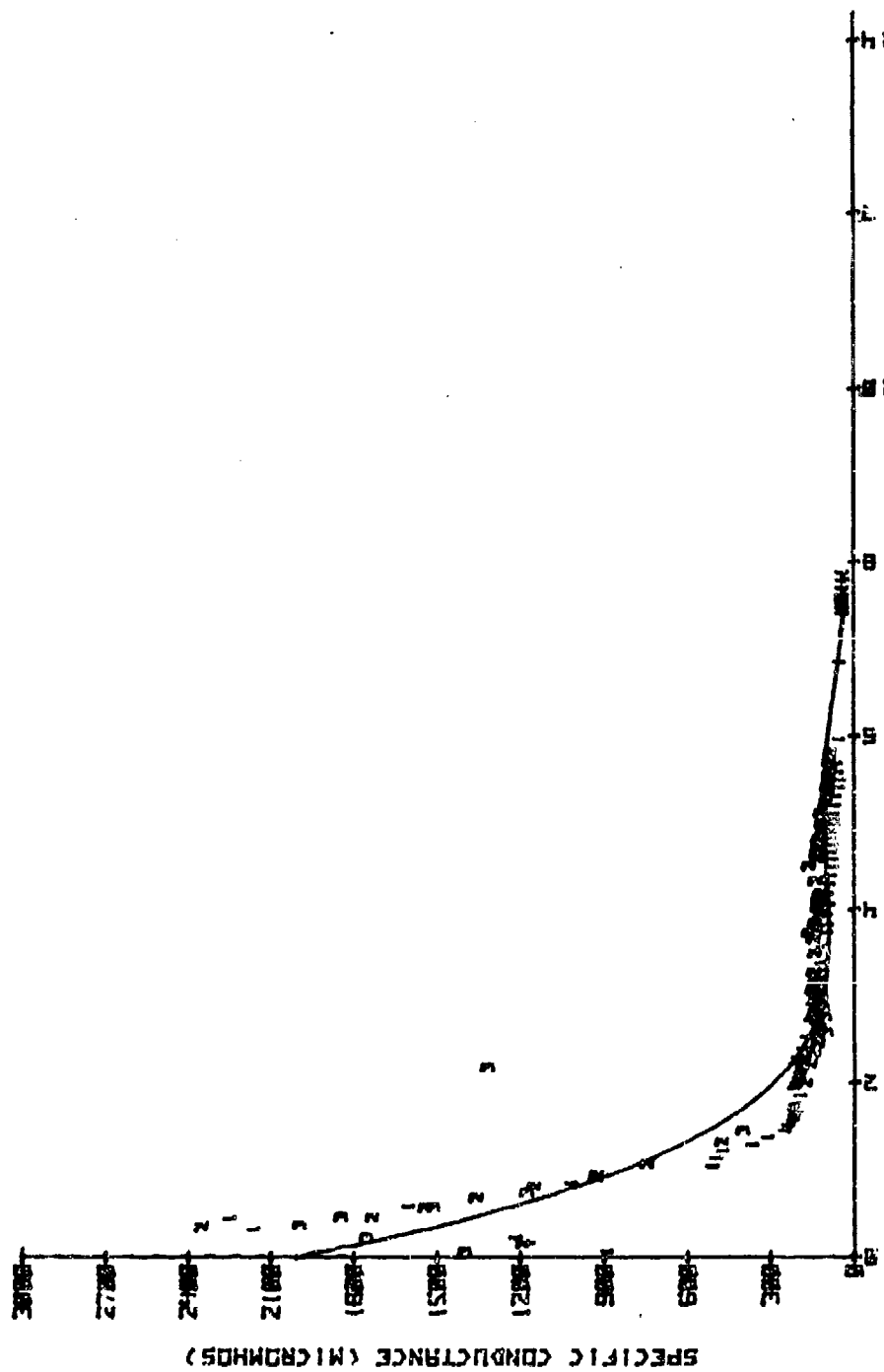


FIGURE 169: CONDUCTANCE OF SOLUTION LEACHED FROM PRINT WASTE & KALKASKA SOIL BY WATER

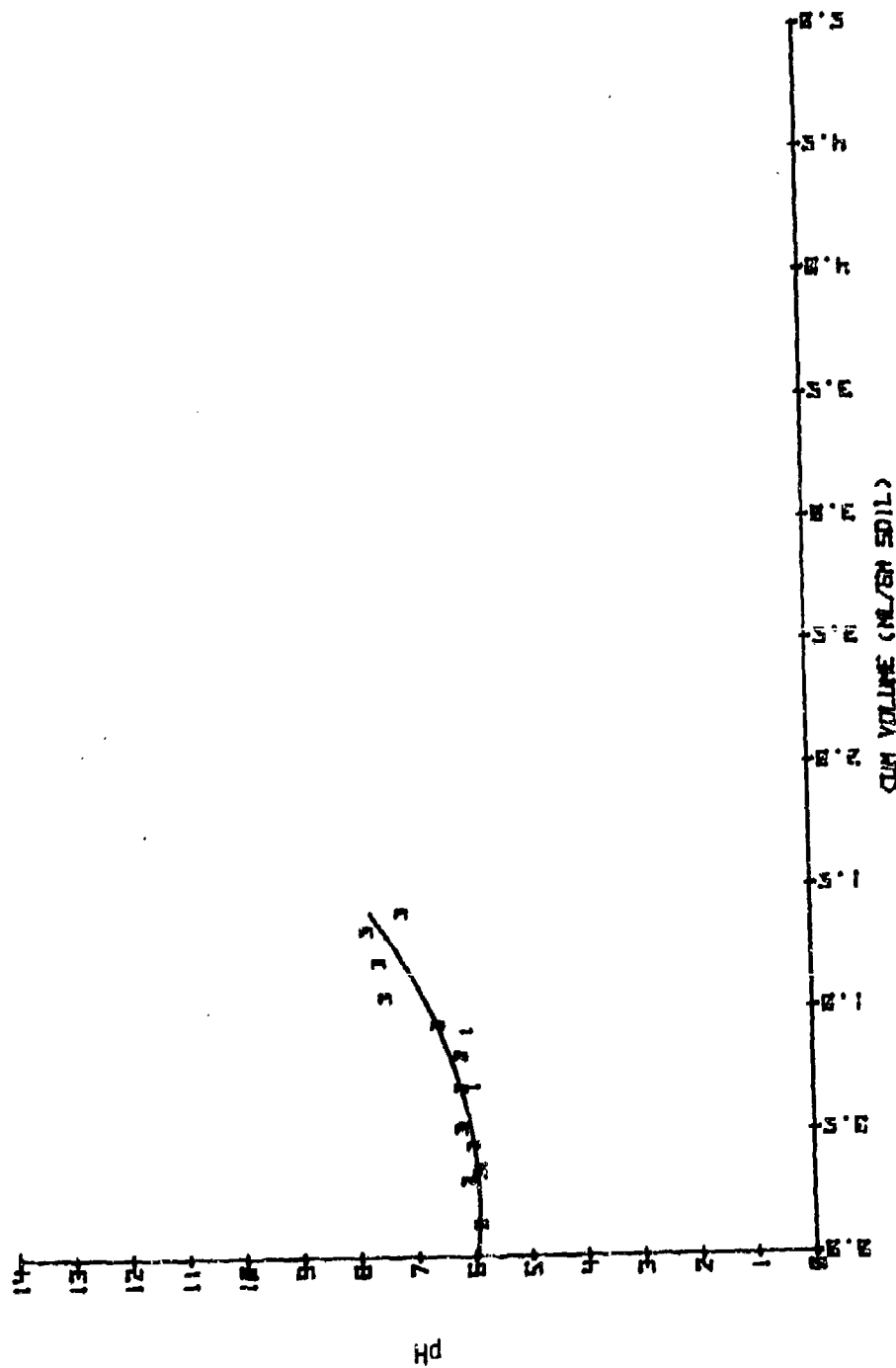


FIGURE 170: pH OF SOLUTION LEACHED FROM PRINT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

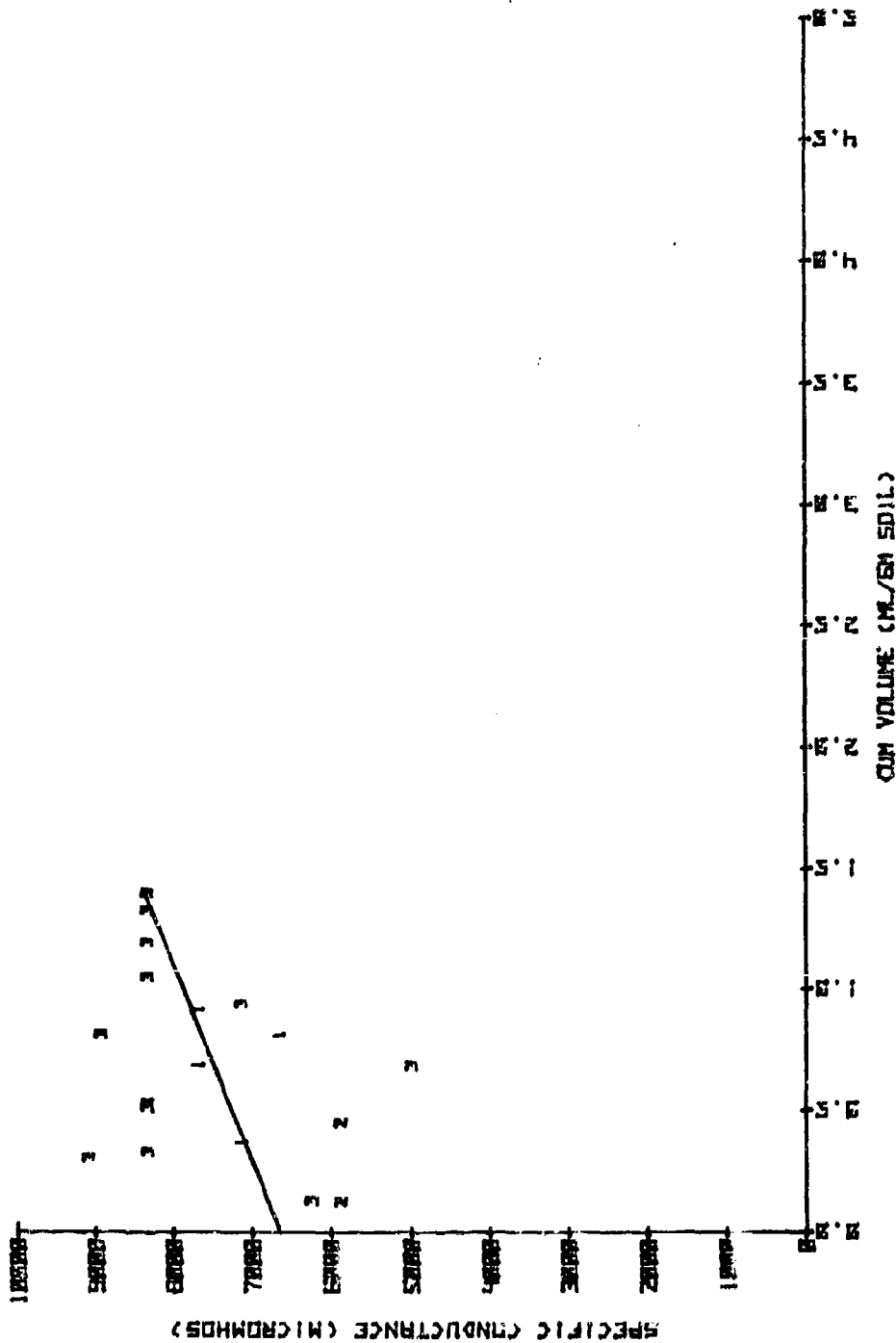


FIGURE 171: CONDUCTANCE OF SOLUTION LEACHED FROM PAINT WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

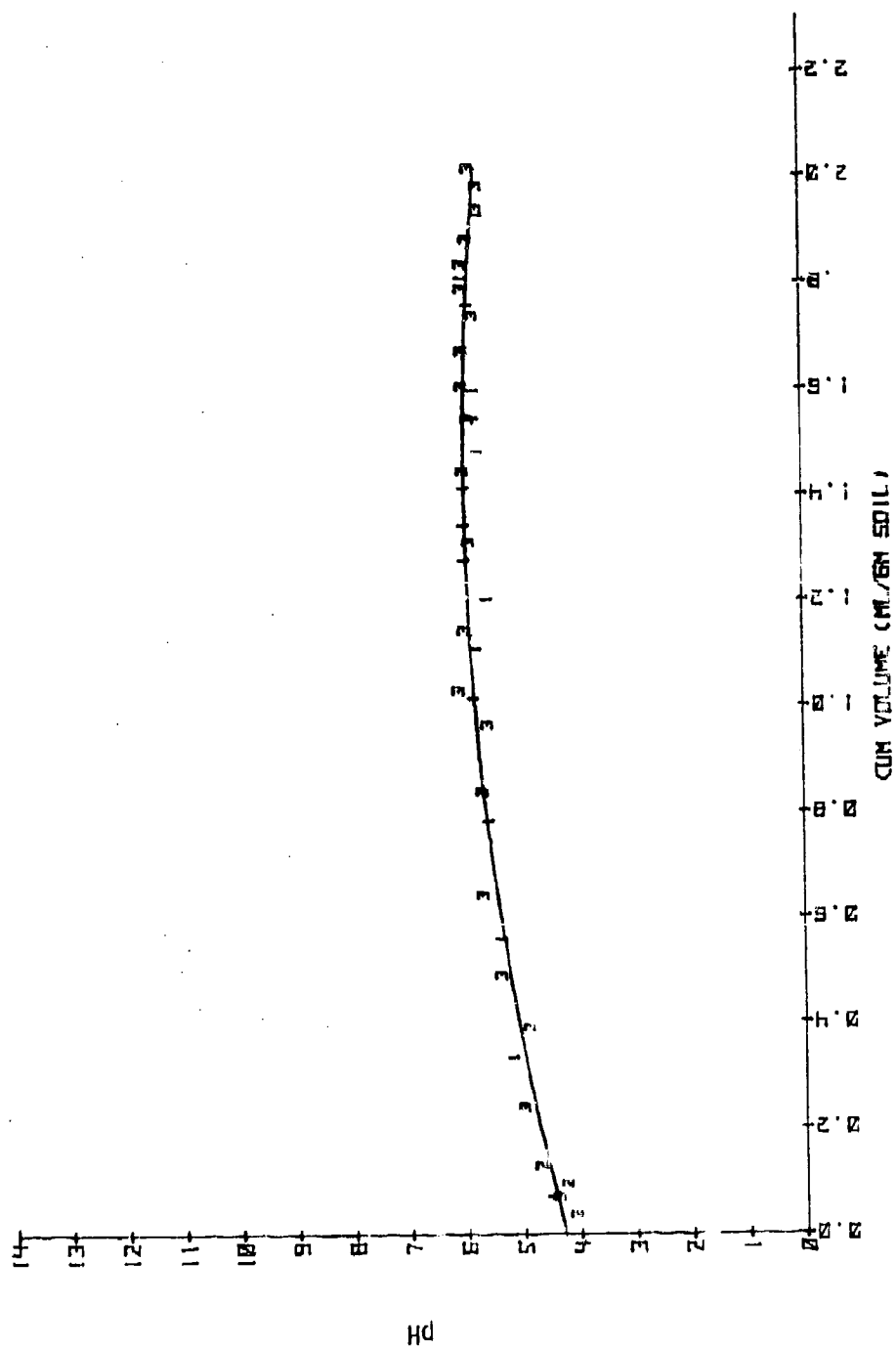


FIGURE 172: PH OF SOLUTION LEACHED FROM PRINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

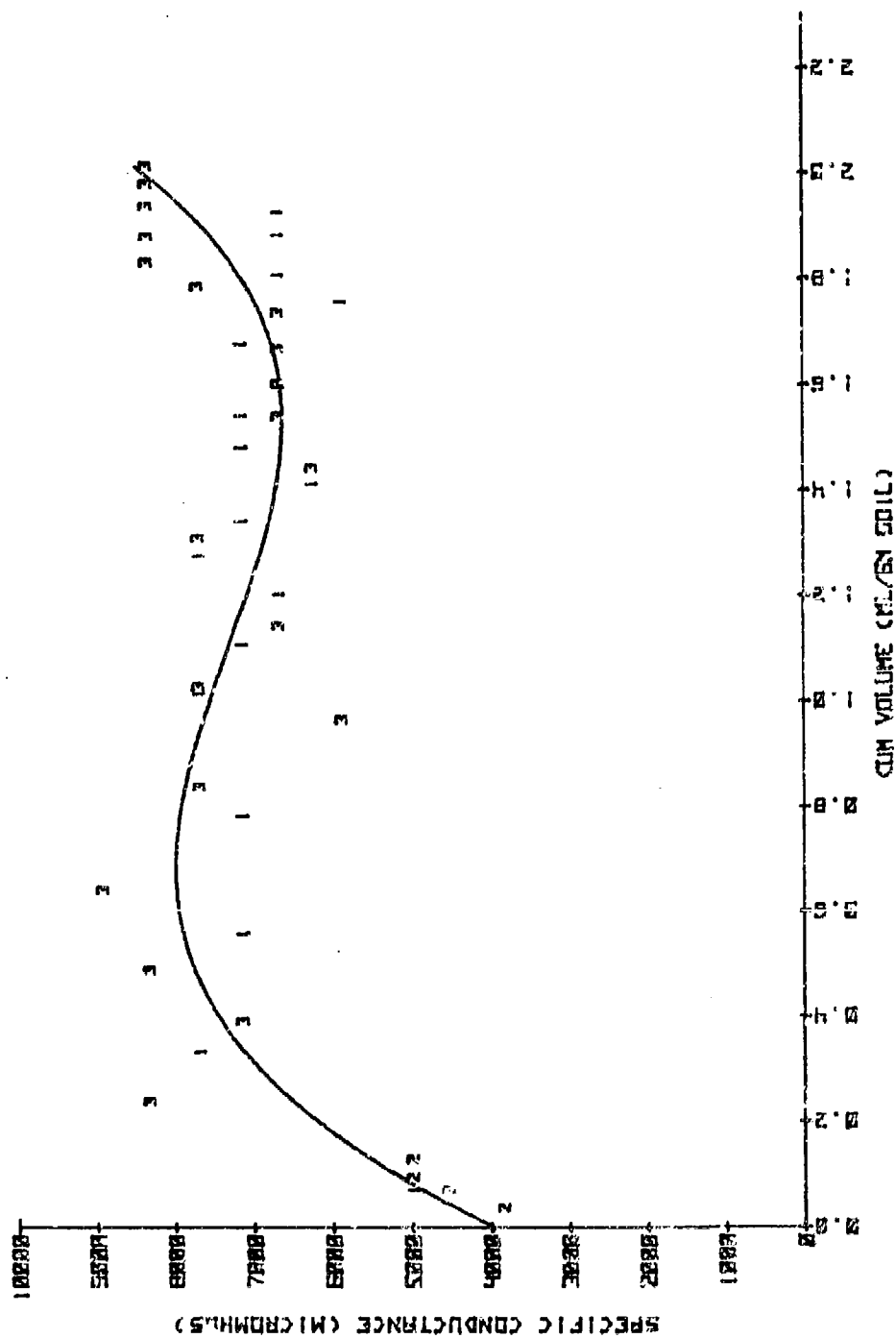


FIGURE 173: CONDUCTANCE OF SOLUTION LEACHED FROM PAINT WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

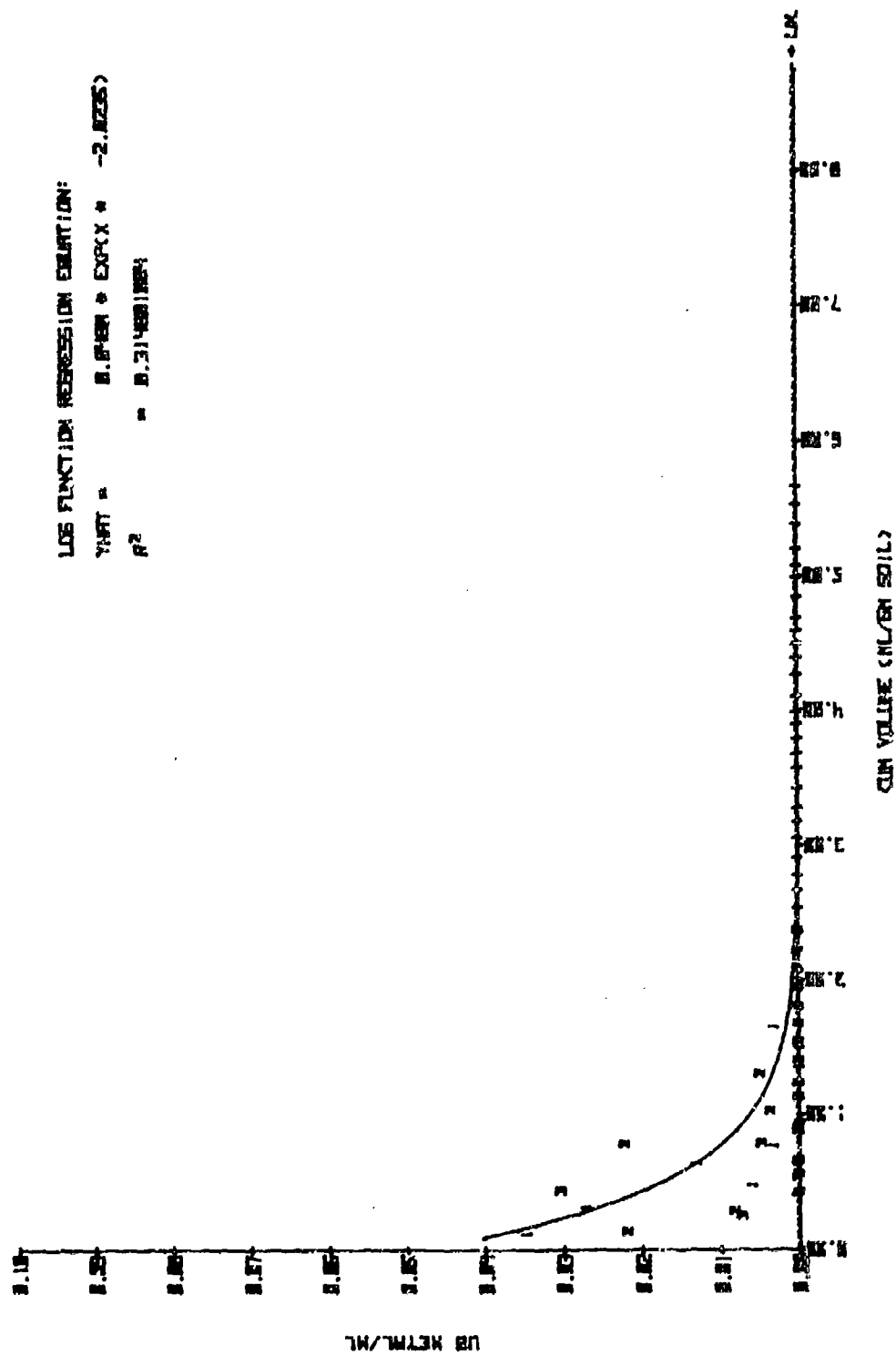


FIGURE 174: MERCURY LEACHED FROM CHLORINE-BRINE WASTE & DAVIDSON SOIL BY LANDFILL LEACHATE

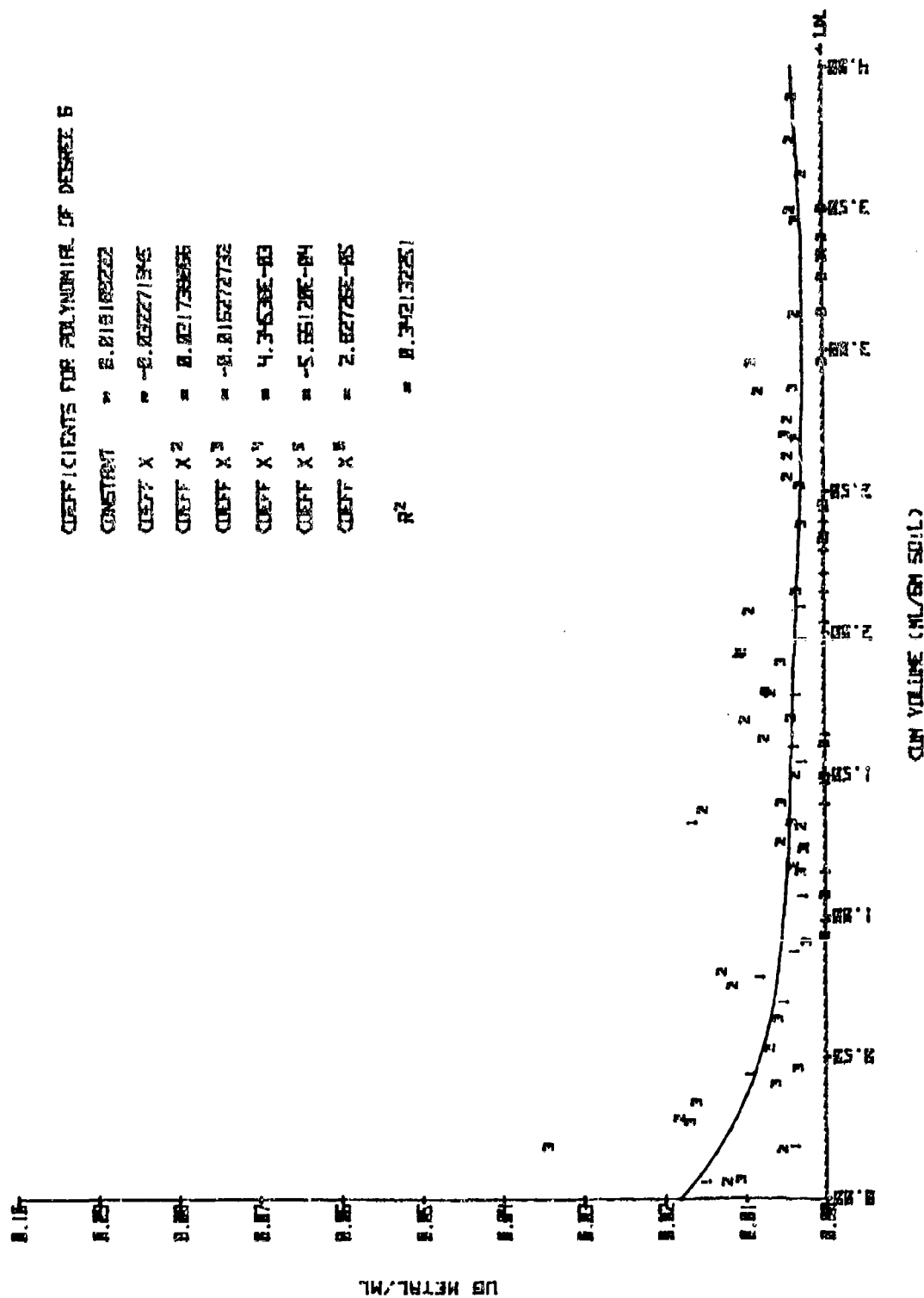
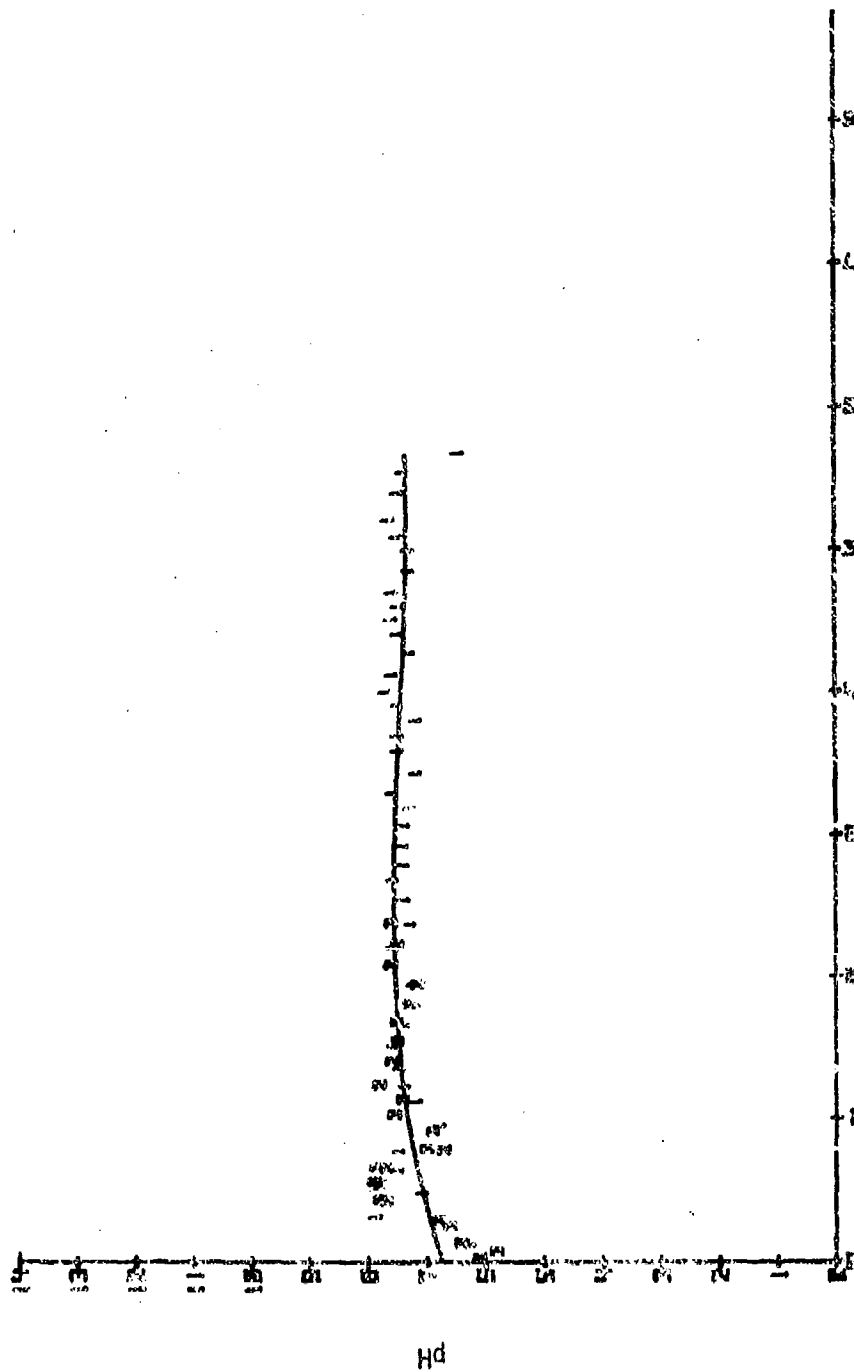


FIGURE 175: MERCURY LEACHED FROM CHLORINE-BRINE WASTE & KALKASKA SOIL BY LANDFILL LEACHATE



ON VOLUME (ML/250 SOIL)
 FIGURE 176: pH OF SOLUTION LEACHED FROM CHLORINE-BRINE
 WASTE & DAVIDSON SOIL BY LANDFILL LERCHITE

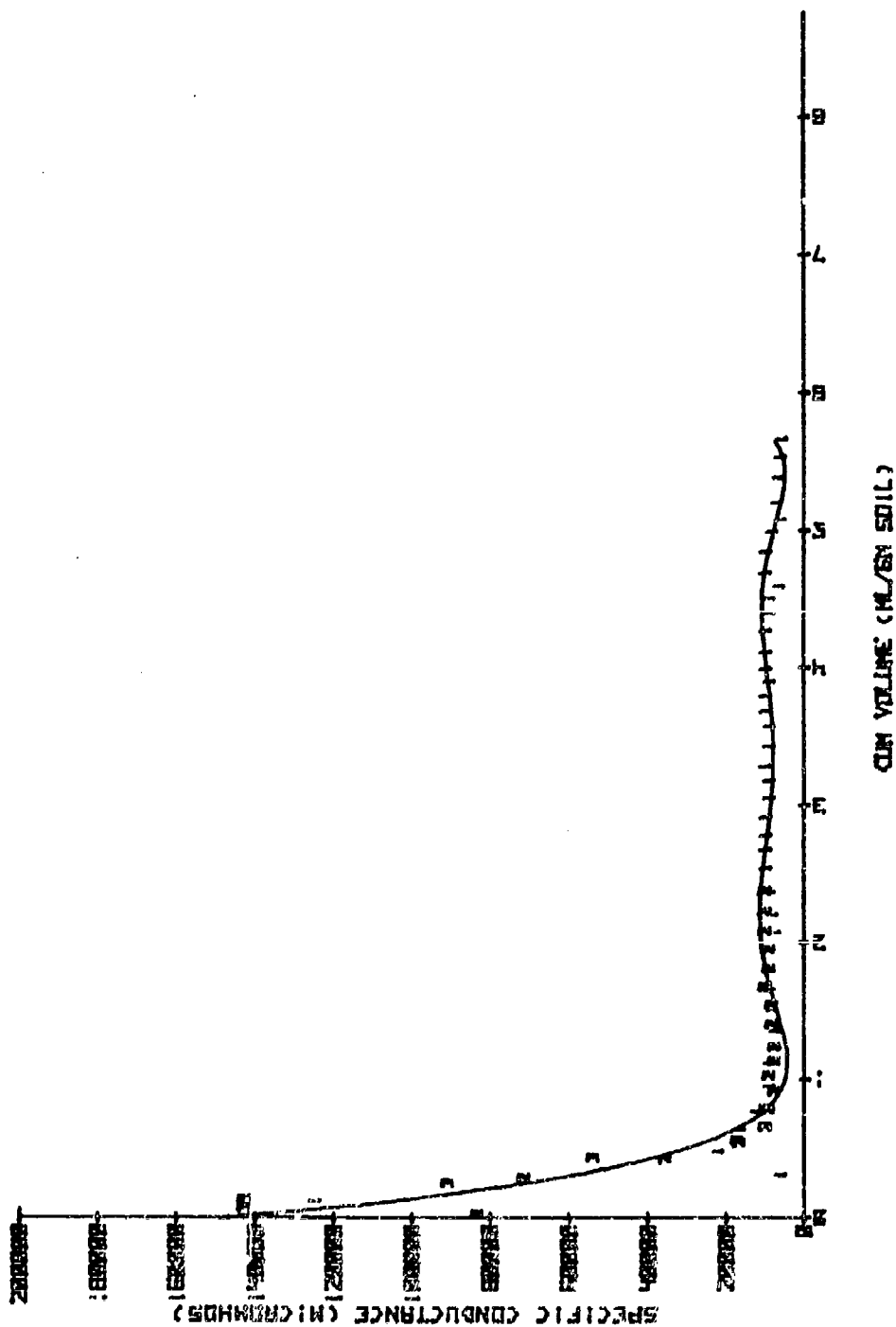


FIGURE 177: CONDUCTANCE OF SOLUTION LEACHED FROM CHLORINE-BRINE
WEISTE & DAVIDSON SOIL BY LANDFILL LEACHATE

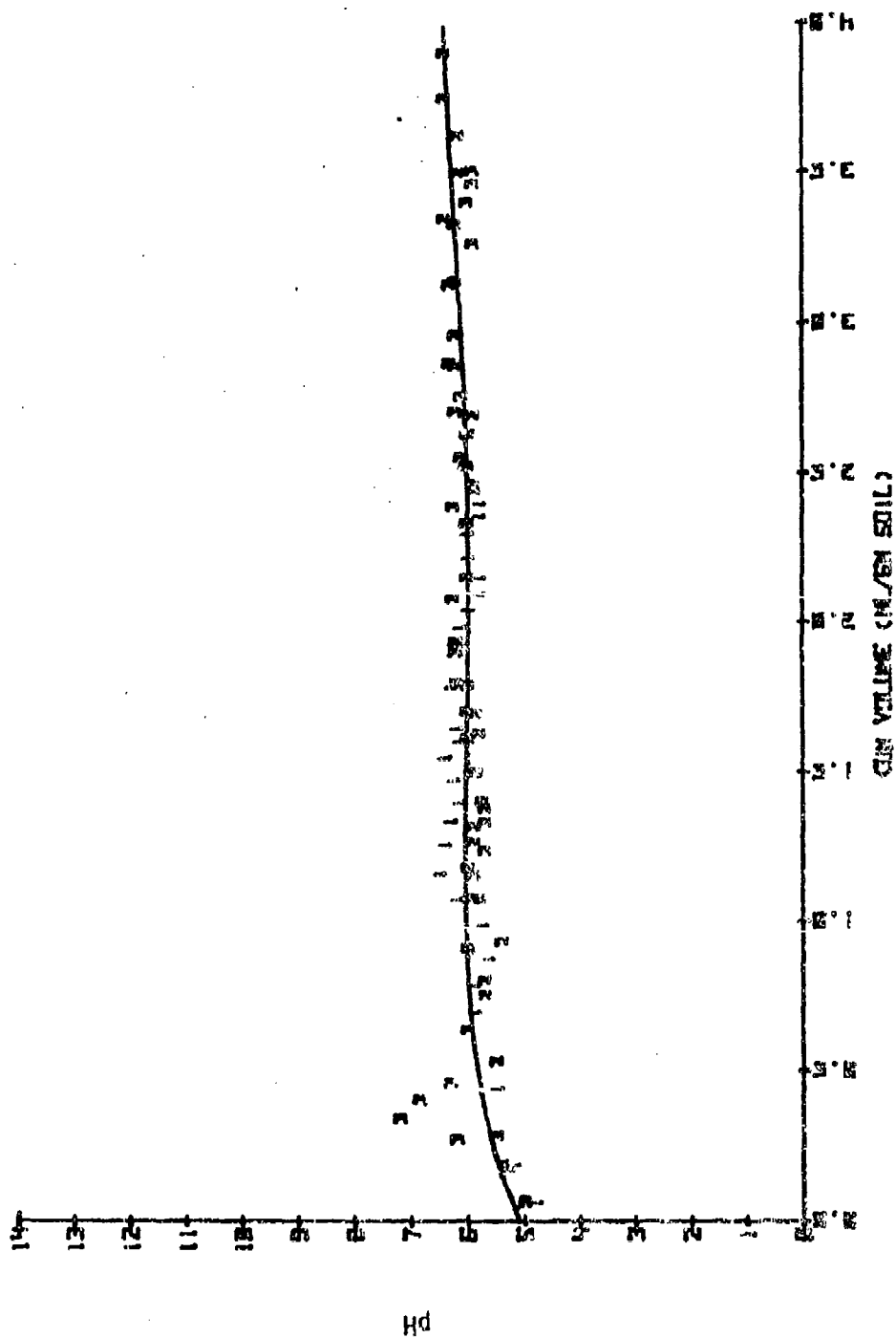


FIGURE 178: pH OF SOLUTION LERCHED FROM CHLORINE-BRINE
WASTE & KALKASKA SOIL BY LANDFILL LERCHATE

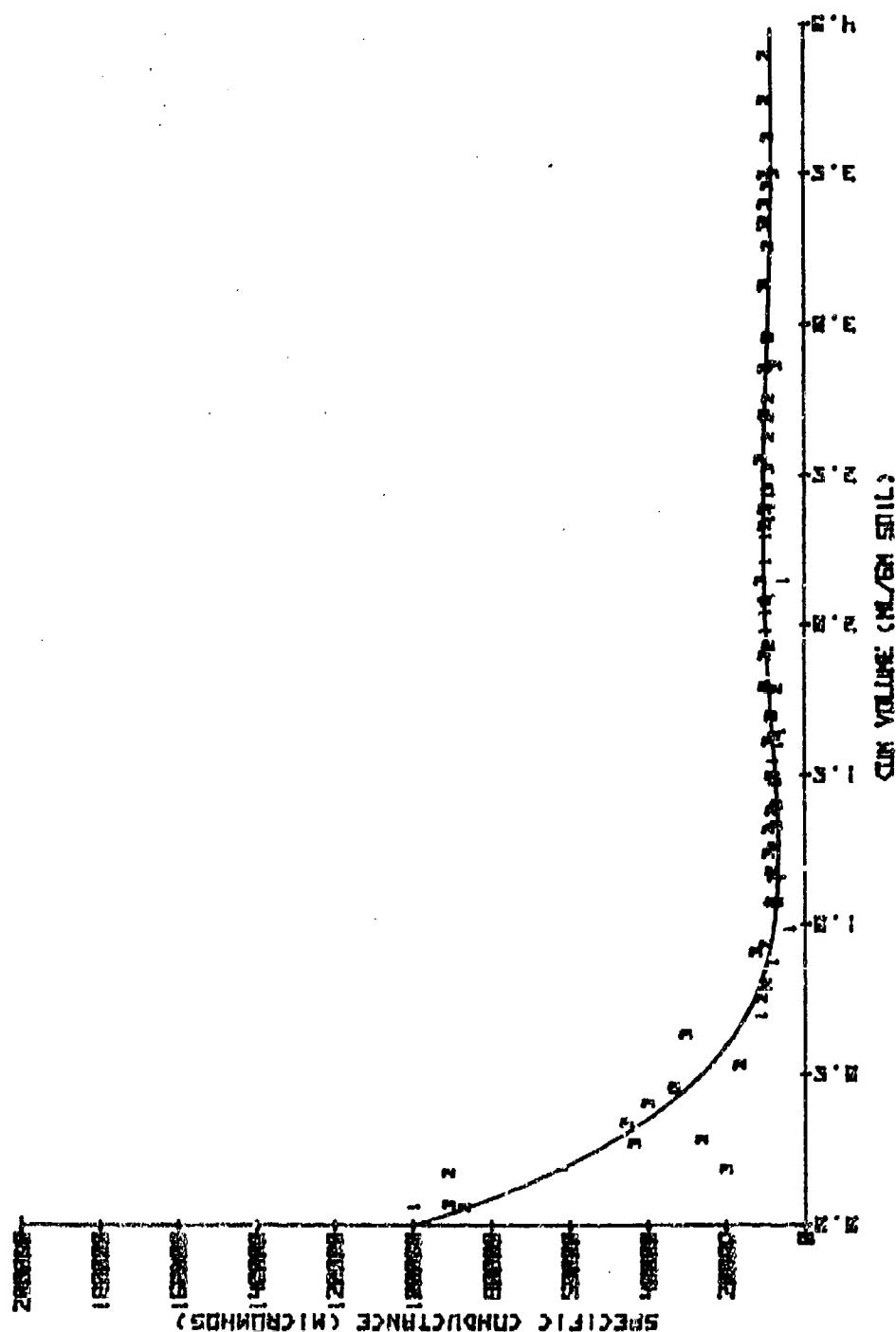


FIGURE 179: CONDUCTANCE OF SOLUTION LEACHED FROM CHLORINE-BRINE WASTE & KALKASKA SOIL BY LANDFILL LEACHATE

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